THE NICKEL BULLETIN

A MONTHLY SUMMARY OF CURRENT INFORMATION

JULY, 1956

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ABSTRACTS OF CURRENT PUBLISHED INFORMATION ON NICKEL AND ITS ALLOYS

GENERAL

Running and Gating of Sand Castings

R. W. RUDDLE: 'The Running and Gating of Sand Castings. A Review of the Literature.'

Inst. Metals Monograph and Report Series No. 19; 183 pp. Published by the Institute, 1956. Price 25/-.

In the course of extensive researches into the production of sand castings, The British Non-Ferrous Metals Research Association has studied various factors affecting the quality of the finished casting, e.g., the preparation of the metal, the mechanism and rate of freezing, method of feeding, and incidence of reactions between the metal and the mould material. As a prelude to extending this work to include laboratory and field study of gating practice, it was decided to review the relevant literature, and the results of the survey are embodied in the present Monograph.

The review opens with a succinct statement on defects which may result from incorrect gating practice, and, as a corollary, the characteristics desirable in an ideal system. Methods employed in experimental study of the flow of molten metals in gating systems are then described, and this chapter is followed by an elementary account of hydrodynamic theory (insofar as it is applicable to the running and gating of castings), and by a discussion, in simple terms, of the mathematical aspects of the fluid dynamics of metal flow. (A more detailed mathematical treatment of hydrodynamics and its application to gating problems is given in an Appendix, which also summarizes knowledge on the hydraulic constants used in the quantitative treatment of the flow of liquid metals.)

Individual types of gating system are then critically discussed in some detail: three chapters deal, respectively, with flow of metal through horizontal gating systems and the design of components of such systems, some special forms of gating system, and the influence of gating on the quality of the product. The final chapter of the Monograph contains a critical assessment of the present state of research on gating, and suggestions for future work which will develop information of practical value to the foundryman. The book is well illustrated, and the review is supported by references to over 120 original items of literature.

Notch-Tensile Characteristics of Nickel-containing Materials

E. J. RIPLING: 'Notch-Tensile Behaviour of Face-Centred-Cubic Metals.'

Amer. Soc. Testing Materials, Preprint 80, June, 1956; 10 pp.

The possibility of developing materials which will be insensitive to adverse loading conditions involving 'notch' effects, and of predicting performance under notch conditions without specific tests, hinges to a large extent on the establishment of a clear relationship between notch sensitivity and the properties characteristic of materials under unnotched conditions. The work reported in this paper is a contribution to this end.

Tests on six face-centred-cubic materials (copper, nickel, Monel, 25-20 chromium-nickel steel, and two aluminium alloys), showed that notch insensitivity of materials of this type, when tested at a constant rate and constant testing temperature, is a linear function of the unnotched strain-hardening exponent.

Electrolytic and Chemical Polishing Methods

W. J. McG. TEGART: 'The Electrolytic and Chemical Polishing of Metals in Research and Industry.'

Published by Pergamon Press, Ltd., London, 1956; 129 pp. Price 30/-.

Since the 'discovery', in the 1930's, of electrolytic polishing, the application of the technique has spread rapidly; it is now a standard procedure for preparation of specimens for microscopical examination, and considerable development has taken place in its industrial applications. The literature of the subject is relatively scattered, but a large proportion of the information available has been gathered together by members of the Division of Tribophysics in the Commonwealth Scientific and Industrial Research Organization, Australia, where the subject has been under study.

The book deals with both the theoretical and the practical aspects, including discussion of the mechanism of the process and factors affecting polishing conditions, laboratory and research applications of electropolishing, and industrial uses of the process. General principles applicable in small- and large-scale use are considered, a review is made of types of solution generally useful in electropolishing, and details are given of conditions suitable for polishing individual types of material, e.g., copper and its alloys, steels, nickel, and other metals and alloys.

Chemical polishing methods not involving the passage of electric current are also reviewed, with particulars of solutions and technique applicable for the treatment of individual materials, in the laboratory or in industrial processing. Appendices contain (1) reference data on rates of anodic dissolution of metals and alloys (with special reference to behaviour in perchloric-acid solutions); (2) information on amounts of metal removed in mechanical polishing and in electrolytic polishing, and (3) details of methods for analysis of sulphuric acid/orthophosphoric acid electropolishing solutions. The *bibliography* attached to the text contains reference to 213 items of literature.

Weld-Cracking Test: Evaluation of Nickel-containing Materials

J. S. BOUDREAU: 'A Weld-Cracking-Susceptibility Test for Sheet Materials.'

Welding Jnl., 1956, vol. 35, Apr., pp. 164S-8S.

The paper describes a test developed in the laboratory of the General Electric Company, Lynn, Massachusetts: it is claimed to give quantitative assessment of the susceptibility of sheet materials to weld cracking. The test consists in applying a measurable, steady tensile load to a specimen of sheet stock while an inert-arc weld is made normal to the axis of loading, without addition of filler material. The load at which cracking is initiated is an index of weld-cracking susceptibility; it is determinable with a minimum of preparation and examination.

Concurrently with development of the testing technique, and as a test of its reliability, evaluation was made of the weld-cracking characteristics of a representative range of nickel-containing high-temperature alloys. In the case of established materials, good correlation was obtained between the indices determined by the new test and their known weldability, and some evaluation tests were made also on a number of modified alloys for which weldability data were not previously available.

Photographs of the test equipment, specimens, and typical test results are included in the report, and charts show the comparative weldability indices of the various materials tested.

Reclaiming of Uranium-contaminated Metals

P. B. KLEVIN and W. B. HARRIS: 'Re-melting May Permit Reclaiming Uranium-contaminated Metals.'

Nucleonics, 1956, vol. 14, Apr., pp. 93-6.

In the interests of economic utilization of scrap without detriment to public health, the work reported was carried out to determine the suitability of uranium-contaminated material for use, as scrap, in normal commercial production. An investigation was made of the amount of uranium present in scrap material which had been used under various conditions, of the effect of re-melting such scrap, and of the amount of uranium present in the re-melted materials. The materials used included nickel, nickel-chromium stainless steel, aluminium, and copper.

The experiments showed that sheet metal $\frac{1}{8}$-$\frac{1}{4}$ in. thick, the surface of which is contaminated with uranium, but which is otherwise relatively clean, may be expected to contain, in the surface layers, 1-10 mg. of uranium per gram of metal. This surface contamination can be removed from stainless steel, nickel and copper, down to a level of about 1 p.p.m., by re-melting. Such an amount cannot be considered hazardous and the re-melted material can therefore safely be used commercially. (The re-melting treatment can be accomplished without hazard to personnel.)

Aluminium scrap which was similarly contaminated did not respond to this treatment. The failure with this metal is attributed to its preferential absorption of oxygen in the presence of almost any other metal, including uranium, a characteristic which would preclude successful use of oxidation as a means of slagging out the uranium.

The re-melted nickel, stainless steel and copper showed residual uranium contamination comparable with National Bureau of Standards pre-1942 standards.

NICKEL

Oxygen Flash Smelting of Sulphides

'Smelting Copper-Nickel Concentrates. Oxygen-Flash Process.'

Metal Industry, 1956, vol. 88, June 15, pp. 493-5.

The article is based on a paper presented to the Canadian Institute of Mining and Metallurgy (see *Trans. Canad. Inst. Min. Met.*, 1955, vol. 58, pp. 158-66). It describes a new process developed by The International Nickel Company of Canada for autogenous oxygen flash-smelting of fine sulphides. Copper flotation concentrate and flux are injected horizontally, with oxygen, into a specially designed reverberatory furnace in which the smelting temperature is maintained solely by the 'flash' combustion of iron and sulphur while the particles are in suspension. Economic operation of the plant requires the provision of low-cost oxygen and presumes a good market for the liquid sulphur dioxide produced as a by-product. The International Nickel Company's hydroelectric system makes possible production of the oxygen at suitable cost, and the sulphur dioxide finds a ready market in manufacture of paper by sulphite mills within a reasonable radius of the INCO plant.

Two major advantages are gained by the new process: the use made of energy from local sources (instead of using imported coal), and the production, locally, of sulphur dioxide for mills which previously had to import sulphur. Saving of coal in 1954 is estimated at 60,000 tons and production of liquid sulphur dioxide, at 70,000 tons, represented the equivalent of 35,000 tons of sulphur.

Early History of the Carbonyl Process of Nickel Extraction

J. M. COHEN: 'The Life of Ludwig Mond.'

Published by *Methuen and Co., Ltd., London*, 1956; 295 pp. Price 22/6.

With introductory note by MR. ROBERT MATHIAS (nephew of Dr. Ludwig Mond) and foreword by SIR ALEXANDER FLECK (Chairman of Imperial Chemical Industries, Ltd.).

As pointed out in the foreword, this biography describes a life typical of the pioneer efforts of determined and imaginative men whose work has laid the foundations of large-scale chemical industry. The story correctly places its main emphasis on the personality, development and achievements of the man himself, but such treatment necessarily involves detailed reference to the varied branches of chemical industry with which Ludwig Mond was associated, and to which he imparted such permanently valuable stimulus. Among the developments of which the story is thus told are those of the ammonia-soda process, the power-gas project, and the early stages of the study of reactions between nickel and carbon monoxide, which resulted in foundation and full commercial exploitation of the Mond carbonyl process for the extraction of nickel, the importance of which has grown continuously to the present day. The story of this development, which was associated with the later years of Dr. Mond's life, provides a particularly interesting example of the highly scientific approach typical of this versatile research chemist, and of his foresight and ability to translate laboratory results into large-scale industrial practice.

Preparation of High-Purity Nickel by Electrolysis

W. A. WESLEY: 'Preparation of Pure Nickel by Electrolysis of a Chloride Solution.'

Jnl. Electrochemical Soc., 1956, vol. 103, May, pp. 296–300.

This is the full form of the paper referred to from abstract source in *Nickel Bulletin*, 1955, vol. 28, No. 11, p. 183. For many research purposes, and for spectrographic reference standards, nickel of the highest possible purity is required in a massive form. The term 'high purity' signifies a widely different level of total impurity content as applied to different metals: in the present state of the art nickel is considered to be of high purity if it contains less than about 100 p.p.m. of spectroscopically detectable contaminants.

Attention is directed to a survey of the literature on preparation of high-purity nickel, made by VAN ARKEL ('Reine Metalle', published by *J. Springer, Berlin*, 1939), and it is noted that no descriptions of the preparation of spectrographically pure nickel have been found in the literature since that date.

The present paper describes a method which has been successfully used in the laboratory of The International Nickel Company, Inc., for the past 15 years. It is claimed that the standard reached is 34 p.p.m. of metallic impurities, and experience in the use of the metal by more than one hundred research workers in universities, industrial laboratories and other institutions substantiates this claim.

The method described has been used by the Company for preparation of three batches of nickel, made, respectively, in 1932 (about 3 kg.), 1940 (about 6 kg.), and 1952 (32 kg.). Full details of the preparation of the latest batch are given.

Mond carbonyl nickel was preferred as the starting material, since it is substantially free from cobalt, which is a most difficult impurity to remove. This nickel is dissolved in hydrochloric acid, to form a concentrated solution of nickel chloride. Copper is removed by a hydrogen-sulphide treatment. Cobalt, iron and zinc are removed by treatment with an excess of nickel peroxide. The purified, concentrated nickel-chloride solution then serves as the stock to feed an electrolysis cell in which the electrolyte is a more dilute, hot solution of the pure nickel chloride, containing boric acid. The latter is added as a buffer to improve the physical properties of the deposit. Insoluble iridium-platinum anodes are used, with a flat, non-reactive cathode sheet, but without a diaphragm of any kind. As electrolysis proceeds the electrolyte becomes depleted in nickel and chlorine in nearly equivalent amounts. These are replaced by addition of the stock purified nickel-chloride solution. The pH reaches a steady-state value, determined by the boric-acid content and the fact that the electrolyte is maintained saturated with chlorine by the anode reaction. The net cell reaction is:

$$NiCl_2 = Ni(metal) + Cl_2(gas)$$

Hydrated nickel peroxide was selected as the oxidizing reagent to be used for purification because it combines four necessary properties, namely, it is a non-contaminating reagent, which can safely be added to the electrolyte in excess, to oxidize iron and cobalt; its reduction products are harmless in a nickel-plating solution; it raises the pH of the solution, to assist in removal of iron and zinc, and it is a colloid which can adsorb impurity cations.

The evidence presented in the paper indicates that by this method nickel of the following purity can be prepared:—

Metallic impurities		Non-metallic impurities	
	p.p.m.		p.p.m.
Al	6	—	—
Co	4	C	26
Cu	4	—	—
Fe	10	H*	(10)
Pb	4	O*	(150)
Mg	1	Cl*	(15)
Si	2	—	—
Sn	3	—	—
	34		

* Not determined.

The carbon content (26 p.p.m.), was reduced to 9 p.p.m. by heating the metal in tank hydrogen, and it is believed that any hydrogen, oxygen and chlorine in the nickel were also substantially reduced by this treatment.

The table below gives the properties of the nickel obtained by the procedure described:—

Lattice constant	3,5168 A.U. at 24·8°C.
Density ..	8·908, computed from lattice constant
Average Coefficient of Thermal Expansion	$10{\cdot}22 \times 10^{-6}$/°C. at −180° to 0°C.
	$13{\cdot}3 \times 10^{-6}$ 0° to 100°C.
	$14{\cdot}63 \times 10^{-6}$ 0° to 300°C.
	$15{\cdot}45 \times 10^{-6}$ 0° to 500°C.
Thermal Diffusivity	0·15885 ± ·00009 cm²/sec. at 25°C.
Thermal Conductivity	0·618 watt/cm./°C. at 25°C.
Electrical Resistivity	0·141 microhm–cm. at 0°C.
	6·844 microhm–cm at 20°C.
Temperature Coefficient of Electrical Resistivity	0·00682/°C. at 0° to 100°C.
	0·00692 (vacuum–annealed)
Coercive Force	2·73 oersteds
Tensile Strength	Annealed: 46,000 p.s.i. (20·50 t.s.i.)
Yield Strength 0·2% offset	Annealed 8,500 p.s.i.
Recrystallization Temperature, after cold rolling 50%	370°C.

Electrolytic and Chemical Polishing Methods

See abstract on p. 122.

Notch-Tensile Characteristics of Nickel-containing Materials

See abstract on p. 122.

Properties and Applications of Nickel and High-Nickel Alloys

See abstract on p. 129.

Magnetostriction in Nickel

G. C. FLETCHER: 'Calculation of Magnetostriction Constants for Nickel.'

Proc. Physical Soc., Sect. A, 1955, vol. 68, Nov. 1, pp. 1066–71.

Calculations were made of the magnetostriction constants λ_{100} and λ_{111} for nickel at 0°K. (−273°C.).

Corrosion of Nickel in Molten Sodium Hydroxide

See abstract on p. 145.

Metallurgy in the Nuclear-Power Field

See abstracts on pp. 123, 139, 141, 145.

Welding, Brazing and Soldering of High-Nickel Alloys

See abstract on p. 130.

Nickel Compounds in Synthesis of Acrylic Esters

K. YAMAMOTO *et al.*: 'High-Pressure Synthesis of Acrylic Esters.

I. Nickel Halide Catalyst.

II. Reaction of Carbon Monoxide with Nickel Halide.

III. Preparation of Triphenyl - Phosphine - Nickel Complexes.

IV. Catalysis with Triphenyl - Phosphine - Nickel Complexes.

V. Properties and Structure of Triphenyl-Phosphine-Nickel Complexes.

VI. Mechanism of the Activation of Carbon Monoxide by Triphenyl-Phosphine-Nickel Complexes.'

Bull. Chemical Soc., Japan, 1954, vol. 27, pp. 491–5; 496–501, 501–4, 505–9, 509–15, 516–20.

Raney Nickel Catalysts

C. AINSWORTH: 'The Reductive Alkylation of Primary Aromatic Amines with Raney Nickel and Alcohols.'

Jnl. Amer. Chemical Soc., 1956, vol. 78, Apr. 20, pp. 1635–6.

Secondary amines form readily from primary aromatic amines, primary or secondary alcohols and relatively large amounts of Raney nickel. Typical experimental data are recorded.

C. AINSWORTH: 'Hydrogenolysis of the Nitrogen-Nitrogen Bond with Raney Nickel', *ibid.*, pp. 1636–7.

Twelve compounds, representing a variety of types but all containing nitrogen–nitrogen bonds, were subjected to the action of a large excess of Raney nickel in the absence of atmospheric hydrogen. In ten of the twelve cases the nitrogen–nitrogen bond was cleaved and the products were identified. Detailed data are reported.

Nickel-Alloy/Ceramic Reactions at Elevated Temperatures

See abstract on p. 147.

Determination of Nickel in Oxidized Films

B. D. BRUMMET and R. M. HOLLWEG: 'Determination of Nickel in Oxidized Films on Nickel Metal.'

Analytical Chemistry, 1956, vol. 28, May, pp. 887–8.

Formation of oxidized films on nickel surfaces has been studied by various investigators, measuring the films, in most cases, either by weight changes or by X-ray or electron diffraction. The latter method necessitates removal of the film from the basis metal, and several techniques for stripping off oxidized films have been described in the literature.

Films of nickel hydroxide can be electrodeposited on nickel from a borate-buffered solution of nickel

sulphate, and in studying the electrochemical characteristics of such films the need arose for estimation of their nickel content. The authors describe a rapid spectrophotometric method which was found satisfactory for this purpose. The solvent used, 0·5 per cent. potassium cyanide, dissolves the oxide film but not the underlying metal. This procedure, which is sensitive to microgram quantities of nickel, may, it is suggested, be usefully applicable to the study of corrosion of nickel surfaces.

Photometric Determination of Nickel and Other Elements in Ferrous Materials

See abstract on p. 134.

Detection of Nickel Carbonyl

J. E. McCARLEY, R. S. SALTZMANN and R. H. OSBORN: 'Recording Nickel-Carbonyl Detector.'

Analytical Chemistry, 1956, vol. 28, May, pp. 880-2.

In oxo and carbonylation reactions using nickel as a catalyst, nickel carbonyl [$Ni(CO)_4$] is generated in the system. This compound is highly toxic, and its presence in the works or laboratory atmospheres therefore constitutes a potential health hazard to personnel. The threshold limit for nickel carbonyl given by the American Conference of Governmental Industrial Hygienists at the time when the work now described was being done was 1 p.p.m.: this requirement was superseded in 1954 by recommendations for a limit of 0·001 p.p.m.

A highly sensitive instrument is obviously required to measure such low concentrations with any degree of accuracy. Chemical methods of analysis are sufficiently sensitive, but are time-consuming, and give only intermittent checks of concentration in the atmosphere. The authors discuss various methods which were used in an attempt to develop an adaptable commercial carbonyl detector, and describe a sensitive stable instrument which was evolved from a consideration of the three following basic principles:—

(1) When a stream of air containing nickel carbonyl impinges on a hot surface, the nickel carbonyl decomposes, yielding metallic nickel and carbon monoxide. The nickel then reacts with components of the atmosphere, to give compounds of nickel which deposit on the hot surface. In the absence of carbon monoxide, the rate of decomposition is proportional to the concentration of nickel carbonyl in the air stream.

(2) For small quantities of deposit, the reflectance of light from the deposit is a measure of the amount of material deposited. Although the reflectance is not a linear function of the quantity of deposit, it varies directly with the quantity of deposit as long as the deposit remains thin.

(3) When a collimated beam of light is incident upon the surface of a dielectric at an angle whose tangent is equal to the refractive index of the dielectric (Brewster's angle), the light is completely polarized by reflection, but at any angle of incidence other than Brewster's angle the reflected light is not completely polarized.

These three principles were utilized in the new instrument in the manner described below:—

A stream of air from the plant atmosphere flows through a nozzle and impinges upon a hot borosilicate glass disc. If nickel carbonyl is present in the stream, a deposit forms on the disc directly below the nozzle. A collimated beam of plane-polarized light is incident upon the disc at the point where the deposit, if any, is formed. The angle of incidence of this beam is the Brewsterian angle for borosilicate glass, and its plane of polarization is perpendicular to the plane of incidence. This arrangement, which corresponds to the crossing of Nicol prisms, results in extinction, so that no light is reflected from the disc. The refractive index μ, and, therefore, the Brewsterian angle (arc tan μ) for the deposit is different from that for glass. Thus, the condition of extinction obtains only for the glass, and any light reflected from the surface is due entirely to the deposit.

The intensity of the reflected light is measured by a recording photomultiplier photometer, which is calibrated in parts per million of nickel carbonyl.

Concentrations in the range 0·05 to 4 p.p.m. by volume can be measured: at 1 p.p.m. the accuracy is $\pm 0{\cdot}2$ p.p.m. or ± 20 per cent. of the amount of carbonyl present. The detector described is sensitive also to iron carbonyl, and it is suggested that it may be useful for detection of other metallo-organic vapours and gases, such as tetraethyl lead.

ELECTRODEPOSITION AND OTHER COATING METHODS

Preparation of Nickel- and Chromium-containing Materials for Plating

E. MORLEY: 'The Chemical Treatment of Nickel, Nickel-Chromium and Chrome-Iron Alloys Prior to Electrodeposition.'

Trans. Inst. Metal Finishing, 1956, vol. 33, pp. 59-61; *Bull. Inst. Metal Finishing*, 1956, vol. 6, No. 1.

Glass-to-metal seals made with copper-plated nickel-iron alloys are required to be robust and to give many years of vacuum-tight service. Their properties depend to a great extent on the quality and adherence of the copper coating, since this surface has to withstand the red heat involved in fusion to glass.

The sole treatment generally used prior to plating a degreased nickel-iron alloy is an anodic etch in a sulphuric-acid solution, but where copper is present, as in some composite components, the anodic etch is followed by etching in nitric-acid solution. In order to render the alloys suitable for matching to certain types of glass, chromium and other metals are in some cases added to the nickel-iron alloy, and due to the presence on the alloy of a protective oxide film (resulting from its chromium content), anodic etching alone no longer ensures the requisite adherence of the copper. It has been found, however, that under certain conditions this oxide film can be

removed by electrochemical reduction. Whereas the original oxide failed to respond to electrochemical reducing treatment, it has been noted that the oxide deposited in sulphuric acid during anodic treatment could be fairly readily reduced. Successful deposition of copper would therefore depend on a double operation, involving anodic treatment in sulphuric acid, followed by cathodic treatment to remove the oxide film formed during the anodic stage. These two operations can be carried out successively, in a single electrochemical unit, by merely reversing the current, but the catnodic treatment is preferably effected in a separate solution, using an insoluble anode. The following solution is recommended:—

Concentrated H_2SO_4	..	2 parts
Distilled H_2O	.. ..	1 part
Adjusted to a final density of		55° Beaumé

The solution is used at room temperature, at a bath voltage of 6. (It has been found that this procedure is suitable also for the preparation of nickel-chromium alloys on which nickel is to be deposited.)

An alternative treatment for nickel-chromium alloys is one which was originally developed for preparation of chromium-iron alloy valve pins. It consists of cathodic treatment, after the anodic step, in a sulphuric-acid solution containing a carefully controlled amount of hydrochloric acid. The optimum composition is:—

H_2SO_4 (sp. gr. 1·84)	..	..	400 cc.
HCl (sp. gr. 1·16)	..	..	100 cc.
Distilled H_2O	..	..	500 cc.

Work so treated can be directly plated from acid copper or high-speed copper-cyanide-Rochelle salt solutions, and the process is suitable also for preparation of a nickel base on which nickel is to be electrodeposited.

Modern Electroplating Plant: Typical Installations

'New U.S. Automatic Plant Incorporates Selective-Cell Plating and Advanced Conveyor System.'

Electroplating and Metal Finishing, 1956, vol. 9, May, pp. 141–3.

This article describes an advanced design of automatic plating plant recently installed by Hanson-Van Winkle-Munning Company at the Oldsmobile works at Lansing, Michigan, U.S.A., to deal with copper-, nickel- and chromium-plating of automobile bumpers of a shape which requires the use of conforming anodes, in order to ensure even distribution of plating. The desired result is obtained by plating in a series of individual cells in which the anodes are arranged round the sides of the cell, to the shape required. In cell-type operation plating is carried out selectively, in many individual cells, with the work stationary during a fixed time cycle, whereas in conventional automatic plating racks travel continuously or intermittently through a large tank.

Operation of the plant is described and illustrated, and some notes are added on the improvement in the quality of coating which has been achieved by the procedure detailed. Four factors are considered to be mainly responsible for the improvement: (1) inspection of the bumper bars after each step in the process, and treatment (by buffing, or by stripping and re-processing) of bars having blemishes; (2) use of the Wes-X. P.R. copper-plating process, by which some degree of levelling is secured, and increased time of copper plating; (3) control of individual plating baths by separate purification systems; (4) cell-type plating, permitting use of conforming anodes.

L. B. WEEG: 'Automation Boosts Plating Capacity.'

Plating, 1956, vol. 43, May, pp. 618–21.

A detailed description is given, with layout drawing, of a large fully automatic nickel- and chromium-plating plant now operating in the works of the National Lock Company, Rockford, Ill., U.S.A. Engineering features of the plant to which particular attention is directed include automatic loading and unloading, bypassing, and stripping, and a safety device which permits the operator to bring moving equipment to a halt from any place on the plating cycle. The article includes particulars of the sequence of operations in copper-, nickel- and chromium-plating and in post-plating treatment. Parts of widely varying design and size are processed, and high quality is achieved in the plated products by means of thorough rinsing (e.g., three rinses after the final chromium plating), immersion of the work with current on, continuous filtration of the solutions, use of high-purity baths, rigid control of all operations, and close inspection and testing of the plated components.

Bright Nickel Plating: Solutions, Technique, Properties of Deposits

T. E. SUCH: 'Bright Nickel-Plating Solutions: Their Choice, Control and Operation.'*

Reprint from *Electroplating and Metal Finishing*, Sept. and Oct., 1955: see abstract in *Nickel Bulletin*, 1955, vol. 28, No. 12, p. 212.

Issued by MOND NICKEL CO., LTD., 1956; Publn. 985, 1956; 22 pp.

Institute of Metal Finishing: Annual Conference

'Institute of Metal Finishing, Annual Conference, Blackpool, May, 1956.'

Electroplating and Metal Finishing, 1956, vol. 9, May, pp. 159–70.

A series of abstracts covers papers presented at the above Conference; major points from the discussion are also summarized. The papers are dealt with in groups, as shown below:—

Bright Anodizing of Aluminium, pp. 159–62.

N. D. PULLEN and B. A. SCOTT: 'Alkaline Electro-Brightening and Anodizing of Aluminium.'

A. W. BRACE and T. S. GROMOBOY: 'Some Studies of Phosphoric Acid-based Chemical Brightening Solutions for Aluminium.'

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F. BAUMANN and H. NEUNZIG: 'Chemically Brightened and Anodized Aluminium and its Employment in Automobile Manufacture.'

G. E. GARDAM and R. PEEK: 'Studies in Bright Anodizing by the Ammonium Bifluoride–Nitric Acid Process.'

This group of papers covers work done in research and commercial establishments in the U.K., and description of a process widely used in Germany.

Chemical Polishing of Steel, p. 162.

K. SACHS and M. ODGERS: 'Smoothing of Mild Steel by Barrel Treatment in Oxalic Acid-Hydrogen Peroxide Solution.'

Miscellaneous Plating Processes

G. GUTZEIT: 'Industrial Nickel Coating by Chemical Catalytic Reduction', pp. 163–4.

(See also *Metal Industry*, 1956, vol. 88, June 15, pp. 499–501).

This paper comprised a review of the development and current stage of knowledge and application of the Kanigen electroless nickel-plating process, which has been developed from the basically similar technique evolved by Brenner and Riddell at the National Bureau of Standards. Some comparison is made between electroless (Kanigen) and electrodeposited nickel coatings.

Plant used for deposition by the Kanigen process is described, and details are given of the essential composition of the solutions and of operating conditions. Full analyses of typical deposits are recorded.

A full report is then made of the properties of Kanigen nickel coatings, including physical, electrical and magnetic characteristics, behaviour at elevated temperatures, resistance to corrosion, mechanical properties, abrasion-resistance, adhesion, fatigue-resistance and resistance to impact. (An appendix to the paper contains a table showing the resistance of chemically deposited nickel-phosphorus alloy coatings to more than thirty corrosives, in varying conditions.)

The next section of the paper is concerned with basis materials suitable for coating by the electroless catalytic process, and finally a review is made of applications in which such coatings can usefully be employed. The limitations, as well as the advantages, of Kanigen plating are discussed, and consideration is given to the economic aspects of the subject. The paper includes much useful information.

Discussion included presentation, by H. C. CASTELL, of comparative data on the tensile strength, hardness, elongation and stress of nickel deposits produced from Watts, chloride, all-sulphate, cobalt-nickel and organic bright-nickel electroplating solutions, of tin-nickel alloy deposits, and of deposits produced by the chemical nickel-reduction process. It was noted that in all respects except elongation the chemical nickel coatings compared favourably with other types. A mechanism of chemical nickel plating, alternative to that described by the author, was proposed by P. HERSCH: comment on his suggestion was made by T. P. HOAR. J. F. KAYSER reported successful results in routine industrial plating by chemical reduction, using a solution varying slightly from the baths referred to in the paper. He forecast a bright future for the process. Other items of discussion centred on limitations imposed by the lack of ductility of the chemical-reduction deposits, and on the suitability of such coatings for specific applications.

H. D. HUGHES: 'Practical Brush Plating', pp. 164–5.

(See also *Metal Industry*, 1956, vol. 88, June 15, pp. 501–2).

This paper dealt with methods developed in France, and embodied in a technique known in England as the Dalic process. Equipment and plating procedure are described. Metals which can be thus deposited include nickel, copper, zinc, chromium, gold, silver, rhodium, platinum, cadmium, lead and indium. The hardness levels typical of the respective coatings are indicated, and applications in which brush plating can suitably be employed are reviewed. For nickel, it is suggested that brush plating is advantageous in building-up of worn or over-machined parts and in nickel-plating prior to tinning of cast iron.

In discussion, reference was made to the potential use of brush plating in coating 'difficult' base materials, e.g., aluminium, titanium and molybdenum; to the possibility of restricting the plating area without the use of stop-off media, and to the possible tendency of brush-plated coatings to porosity.

A. E. DAVIES and R. M. ANGLES: 'The Electrodeposition of Tin–Zinc Alloys from Stannate–Complexone Solutions', p. 165.

C. P. BRITTAIN and G. C. SMITH: 'A Preliminary Investigation of the Formation of Cracks in Hard Chromium Electrodeposits and the Evolution of Hydrogen during Deposition', pp.165–6.

Electroplating Plant

J. CHADWICK: 'Automatic Plant for Bright Zinc Plating', p. 166.

H. C. CLEMENTS: 'The General and Chemical Engineering Aspects of Electroplating Plant', pp. 166–8.

Organic Finishing, pp. 168–70.

T. R. BULLETT: 'Laboratory Evaluation of Paint Durability.'

E. M. ELLIOTT: 'Polytetrafluoroethylene Dispersions in Metal Finishing.'

W. F. HIGGINS: 'The Painting of Magnesium Alloy Surfaces and the Principle of Surface Sealing.'

P. SPIRO: 'Electroformed Spray Masks.'

All the above papers and discussions will be published, in full, in the ***Transactions of the Institute of Metal Finishing***, 1956, volume 33, which will also contain the Hothersall Memorial Lecture, entitled 'Of Nickel Atoms, Ions and Electrons', delivered at the Conference by Dr. W. A. WESLEY, of The International Nickel Company, Inc.

Stress in Electrodeposited Coatings

J. B. KUSHNER: 'Stress in Electrodeposited Coatings; its Significance and Measurement.'
Metal Finishing, 1956, vol. 54, Apr., pp. 48–51, 57; May, pp. 58–63.

A review article. The first part deals with the nature of stress, its effects on adhesion, and its influence as a contributory cause of cracking, blistering, distortion, corrosion, and loss of fatigue-resistance. In the second part consideration is given to the effect, on development of stress, of plating variables such as temperature, current density, agitation, composition of (nickel-plating) baths, and thickness of deposit. This is followed by a review of theories which have been advanced to explain the occurrence of stress in electrodeposited coatings, and of some methods which are used to evaluate the amount of stress present.

Preparation of High-Purity Nickel by Electrolysis

See abstract on p. 124.

Electroplating of Niobium

J. G. BEACH and C. L. FAUST: 'Electroplated Metals on Niobium.'
U.S. Atomic Energy Commission Publn. BMI-1004, May 24, 1955.

The investigation reported was undertaken in connexion with the need for electroplating of niobium as an intermediate step in cladding of this metal with other metals or with alloys. Search of the literature revealed no details of technique by which adherent electrodeposits on niobium could be obtained, but methods developed for plating on tungsten, tantalum and zirconium were examined with reference to their possible adaptation to niobium.

Niobium, tantalum and zirconium easily form hydride compounds, and in view of the danger of released hydrogen under a coating destroying the bond between base and plating, the formation and decomposition of hydrides, the solubilities of hydrogen, and the permeability of hydrogen through the coating were subjected to close study.

It was found that niobium could be activated for plating by electrolytic treatment in concentrated hydrofluoric-acid solution at room temperature, using alternating current. Grey smut formed during this etching stage could be easily removed by immersion for a few seconds in a nitric/hydrofluoric acid solution. After water rinsing, the niobium was electroplated with nickel or iron from sulphate-chloride solutions.

The coatings so produced could be peeled off, but only with difficulty. They were then baked, in vacuo, at 400°F. (204°C.) for two or twenty-two hours and subsequently heated to 1300°F. (704°C.) for one hour.

Alloying of nickel which occurred during heating at 1300°F. (704°C.) resulted in formation of a weak nickel-rich phase, and it is considered that for high-temperature applications this system offers little promise. Although some alloying of iron and niobium probably occurred during the high-temperature treatment, it was not evident on metallographic examination. The bond between the iron and the niobium was excellent, and it is therefore concluded that an electrodeposited layer of iron may be suitable as a bonding medium between cladding and the niobium base.

U.S. Specifications for Metal Coatings and Surface Finishes

N. E. PROMISEL: 'Digest of Government Specifications. Metal Coating and Surface Treatments (other than Organic Coatings).'
Plating, 1956, vol. 43, May, pp. 628–31.

This is one of a series of digests intended to provide an accurate, up-to-date survey of the most widely used U.S. Government specifications in the fields indicated. The current section includes details of Federal specifications for cadmium and zinc coatings, electrodeposited nickel coatings on steel and non-ferrous materials, phosphate and oxide coatings on steel, silver plating, porous chromium, spray-metallized coatings and coatings for aluminium- and magnesium-base materials.

NON-FERROUS ALLOYS

Properties and Applications of Nickel and High-Nickel Alloys

A series of publications recently issued by MESSRS. HENRY WIGGIN AND COMPANY, LTD. contains a complete revision of mechanical and physical property data for nickel, Monel, K Monel, and Inconel. The information given represents a correlation of the latest available information, compiled on the basis of laboratory tests and service experience. A number of typical applications of the materials are illustrated.

These publications, a list of which is given below, supersede those in similar categories previously published by the Company.

'Nickel. Properties and Applications.' *Publn.* 1040.*
'Monel and K Monel. Properties and Applications.' *Publn.* 1042.*
'Inconel. Properties and Applications.' *Publn.* 1041.*
See also Data Sheet on Inconel. *Publn.* 1043.*
'The Engineering Properties of Monel, Nickel, Inconel.' *Publn.* 1038.*
'K Monel. Physical and Mechanical Properties: Data for the Design Engineer.' *Publn.* 1039.*

Constitution of the Ni_3Al Phase of Nickel-Aluminium Alloys

See abstract on p. 139.

Lattice Spacing in Nickel-Copper Alloys

B. R. COLES: 'The Lattice Spacings of Nickel-Copper and Palladium-Silver Alloys.'
Jnl. Inst. Metals, 1955-56, vol. 84, May, pp. 346–8.

A general survey of the physical properties of nickel-copper and of palladium-silver alloys had led to the

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conclusion that the electronic structures of the two systems show important differences, in spite of the analogous positions in the Periodic System occupied by the component elements (*Proc. Physical Soc.*, 1952 (B), vol. 65, p. 221). In particular, it appeared probable that in palladium-silver alloys containing more than about 60 per cent. silver no unoccupied states exist in the 4*d*-band at normal temperatures, whereas empty 3*d*-band states persist in nickel-copper alloys up to copper contents of at least 90 per cent. Previous lattice-spacing measurements on the latter alloys had, however, been interpreted in terms of the filling of the 3*d*-band at 60 per cent. of copper.

The present paper reports measurements of the lattice spacings, at room temperature, as a function of composition, in both alloy systems. A marked change of slope of the lattice-spacing/composition curve was found in the palladium-silver alloys near the composition (60 per cent. of silver) where other properties indicate that the *d*-band becomes fully occupied. In the nickel-copper system, the most marked change of slope occurs at the composition (35 per cent. of copper) where the Curie temperature of the alloys reaches room temperature. The total changes in spacing in the two systems are discussed in terms of theories of the contributions of the *d*-bands to the cohesion.

Nickel-Thorium Alloys

J. V. FLORIO, N. C. BAENZIGER and R. E. RUNDLE: 'Compounds of Thorium with Transition Metals. II. Systems with Iron, Cobalt and Nickel.'

Acta Crystallographica, 1956, vol. 9, Apr. 10, pp. 367–72.

In 1952 the authors reported a crystallographic study of intermetallic compounds occurring at room temperature in the binary systems of thorium with iron, cobalt and nickel ((*U.S. Atomic Energy Commission* Publn. ISC-273, 1952: see *Metallurgical Abstracts*, 1954, vol. 21, p. 526).

This second paper gives details of the structures of these compounds. Certain relationships among the compounds were observed.

Nickel-Tin Alloys

F. LIHL and H. KIRNBAUER: 'Investigation of Binary Metallic Systems, using the Amalgam Process: the Nickel-Tin System.'

Monatshefte Chemie, 1955, vol. 186, pp. 745–51.

For alloys containing up to 50 per cent. of tin the results are in close agreement with previously published reports. At higher tin contents the authors observed, in addition to the β, γ and δ phases already recognised, a fourth phase, for which, on account of its close structural relationship with the δ phase, the designation δ_1 is proposed.

Running and Gating of Sand Castings

See abstract on p. 122.

Notch-Tensile Characteristics of Nickel-containing Materials

See abstract on p. 122.

Electrolytic and Chemical Polishing Methods

See abstract on p. 122.

Constructional Materials for Use in Petroleum Refineries

See abstract on p. 148.

Metallurgy in the Nuclear-Power Field

See abstracts on pp. 139, 141, 145.

Nickel-containing Aluminium Alloy for Distilled-Water Service

See abstract on p. 145.

Welding, Brazing and Soldering of High-Nickel Alloys

HENRY WIGGIN AND CO. LTD.: 'Welding, Brazing and Soldering of Wiggin Nickel Alloys.'

Publn. 954*, 1956; 73 pp.

This publication gives general guidance on the welding, brazing and soldering of Monel, nickel, Inconel, Corronel B, Nimonic alloys, and the alloys of the Brightray series. Following a note on the properties of the individual materials, consideration is given to factors which affect welding, e.g., the condition of the material, heat-treatment, design of joints, and surface preparation and finish.

All the usual welding processes may be used for nickel and these high-nickel alloys: choice of the method best suited to individual applications is governed mainly by the thickness of the material and the use to which the completed part is to be put. Detailed recommendations are made with regard to oxy-acetylene, metallic-arc, carbon-arc, inert-gas-arc, atomic-hydrogen, and resistance welding; recommended materials are described and design of joints is illustrated. Other subjects dealt with include the welding of dissimilar materials, the lining of steel vessels, and brazing and soldering of the respective materials.

Nickel-Alloy/Ceramic Reactions at Elevated Temperatures

See abstract on p. 147.

NICKEL-IRON ALLOYS

Solubility of Graphite in Nickel-Iron Alloys

E. T. TURKDOGAN, R. A. HANCOCK, S. I. HERLITZ and J. DENTAN: 'Thermodynamics of Carbon Dissolved in Iron Alloys. Part V. Solubility of Graphite in Iron-Manganese, Iron-Cobalt, and Iron-Nickel Melts.'

Jnl. Iron and Steel Inst., 1956, vol. 183, May, pp. 69–72.

(Earlier sections of this investigation covered

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solubility of graphite in iron, iron-silicon, iron-phosphorus, iron-sulphur and iron-silicon-phosphorus melts. References to the original work are given in this paper. (*See also* related paper abstracted in *Nickel Bulletin*, 1956, vol. 29, No. 6, p. 103.)

The solubility of graphite in binary alloys of iron with manganese, cobalt, and nickel was determined at temperatures up to 1550°C. over the entire composition ranges. It was found that manganese increases graphite solubility in iron, whilst cobalt and nickel decrease it. In the case of iron-nickel melts at 1350° and 1550°C. the solubility reaches a minimum value at about 80 per cent. nickel; reference is made to the anomalous behaviour of nickel in chromium-oxygen and iron-oxygen melts. The change of graphite solubility in iron on adding a second element, *X*, is related to the atomic number, crystal radius, and second ionization potential of the element *X*.

Heat Changes in Nickel-containing Alloys of High Coercivity

L. F. BATES and A. W. SIMPSON: 'The Thermal Effects associated with the Magnetization of High-Coercivity Materials.'

Proc. Physical Soc., Sect. B., 1955, vol. 68, Nov. 1, pp. 849–58.

Heat changes accompanying magnetization processes in materials of high coercivity, over a field range of 4,000 oersteds, were studied by a new method, which is described. The materials used in the investigation were five different types of nickel-aluminium-iron-base alloys (Alnico, Alni, and Alcomax II, III and IV, all of which had undergone normal industrial heat-treatments), Gecalloy (which contains approximately 76 per cent. of extremely finely divided iron, the ellipsoidal particles of which are suspended in a plastic binder), and a 50-50 at. per cent. cobalt-platinum alloy. The results of the experiments are in good agreement with the Stoner and Rhodes theory of magnetization processes in materials of high coercivity.

Effect of Nuclear Radiation on the Elastic Properties of Nickel-Iron Alloy

A. CHARLESBY, N. H. HANCOCK and H. C. SANSOM: 'Effect of Atomic-Pile Radiation on the Elastic Modulus of an Austenitic Steel.'

Jnl. Nuclear Energy, 1955, vol. 1, June, pp. 264–73.

Previous experimental work has shown that, with the possible exception of unstable alloys, the effects of atomic-pile radiation on the mechanical properties of metals and alloys are usually small. Highly accurate methods of measurement are therefore essential for tracing any positive and repeatable effect outside the limit of experimental error. Among the mechanical properties which could be studied from this point of view, Young's modulus is considered to have two advantages: its intrinsic interest as a fundamental property of the solid state, and the fact that it can be measured with a high degree of accuracy. The procedure used in the experiments described in this paper involved the use of a clock, embodying a hairspring of Elinvar (nickel-iron alloy having closely controlled thermal coefficient of expansion). The use of this method of test was based on the argument that a clock is, in essence, a highly accurate, finely designed and compensating instrument for measuring Young's modulus of the hairspring, and that if such a clock is irradiated in an atomic pile, any change in modulus of the hairspring would show up as a change in timekeeping. Necessity for winding was obviated by using a car clock which would run indefinitely from a d.c. supply, and timekeeping could be checked by counting the pulses of current required to run the clock.

Full details are given of experimental set-up and technique used in tests, in which the behaviour of the Elinvar springs was studied at 62° and 70°C. over a period of up to 8 weeks' irradiation in the atomic pile (i.e., for a total integrated flux of 10^{19} neutrons/cm^2).

Over a period of three weeks two specimens showed a decrease of less than 0·1 per cent. in elastic modulus, and in a third specimen the decrease was about 0·3 per cent. Further irradiation, to a total period of six weeks, restored the modulus to its original value. The changes resulting from irradiation are not considered to be statistically significant.

Nickel-Alloy/Ceramic Reactions at Elevated Temperatures

See abstract on p. 147.

CAST IRON

Corrosion-Resisting Characteristics of Cast Irons

R. I. HIGGINS: 'The Corrosion of Cast Iron.'

Brit. Cast Iron Research Assocn., Jnl. of Research and Development, 1956, vol. 6, Feb., pp. 165–77; *Research Report* No. 422.

This is essentially a factual presentation of the corrosion-resisting characteristics of various grades of cast iron. For more detailed discussion of the mechanism of the corrosion processes involved, and their rate-controlling factors, attention is directed to standard textbooks.

The subject is treated in the following sections:—

(1) Unalloyed Cast Irons
Including remarks on the influence of the metal and of its environment.

(2) Low-Alloy Cast Irons
Including notes on the general effect of low alloy additions on the general structure of the iron, and the specific influence of copper, nickel, chromium and molybdenum.

(3) High-Alloy Cast Irons
Special reference is made to materials of the Ni-Resist (high-nickel), Nicrosilal (high-nickel, high-silicon), high-silicon, and high-chromium types.

The behaviour of materials within these groups, in acid and alkaline media, in salt solutions, in industrial waters, and in atmospheric conditions, is reviewed, and the importance of the high-alloy irons to the chemical-engineering industries is indicated.

CONSTRUCTIONAL STEELS

Stress-Strain Characteristics of Nickel-Alloy Steels

H. C. BARON: 'Stress-Strain Curves of Some Metals and Alloys at Low Temperatures and High Rates of Strain.'

Jnl. Iron and Steel Inst., 1956, vol. 182, Apr., pp. 354-65.

Rates of straining encountered in various branches of engineering vary from about 10^{-11} to 10^{4} in./in./sec. The lower part of this range lies within the field of creep (with which this paper does not deal) and at the highest rates in the scale difficulties arise due to stress-wave propagation phenomena and inertia effects. The two rates chosen for use in the present investigation were approximately 10^{-3} and 10^{2} in./in./sec., the lower value being typical of 'static' tensile tests (as found, for example in components of many large structures such as bridges and cranes), and the higher value of the order attained in wire drawing and rolling, and under impact conditions.

Using such conditions, comparative tensile tests were made on Armco iron, mild steel, a 0·34 per cent. carbon steel, a 2·5 per cent. nickel nickel-chromium-molybdenum steel (in two conditions), 18-8-type chromium-nickel steel, an aluminium alloy of the Duralumin type, tough-pitch copper, and leaded brass. All the materials were in the form of $\frac{3}{8}$-in. or $\frac{1}{2}$-in. diameter bar, and in all cases the tests were made at three temperatures: 20°, −78° and −196°C. For the tests at the higher speed an impact method was used, by which a conventional test piece is broken in one blow and the load on the test piece is measured by a weighbar.

The stress-strain curves show that rate of strain and temperature exert a marked effect on iron and on the softer ferritic steels. In dynamic tests below a critical temperature all the ferritic materials exhibit a type of premature failure in which the strain is entirely localized to a short neck: this is shown to be a consequence of the adiabatic nature of this test. Variation of upper yield stress with temperature and strain rate appears to obey an activation-energy relationship over part of the range of stress. Within this range the activation energy for yielding varies with the stress in the manner predicted by Cottrell and Bilby. It is considered that the divergence from theory at low stresses may be due to simultaneous strain-ageing, whilst at high stresses brittle fracture or twinning eventually intervene before the upper yield point is reached.

An aluminium alloy of the Duralumin type showed a yield point which varied with rate of strain and temperature in a manner similar to that observed for steels, but anomalies, probably caused by a strain-ageing process, were found in slow tensile tests at 20°C. With annealed tough-pitch copper the proof stress appears to be little affected by strain rate and temperature, but the rate of strain hardening is strongly affected by both variables. Strain rate has relatively little influence on the behaviour of annealed brass. The data obtained on the austenitic stainless steel are correlated with observations made by the author and others on structural transformations occurring in such materials under deformation. Among the findings on this material are (1) that the static test at 20°C. resulted in more transformation to martensite than did the dynamic test, a result which would be anticipated in view of the rise in temperature involved in the dynamic test, and (2) that a yield phenomenon observed at −196°C. was associated with rapid transformation of austenite.

Hardness of Low-Alloy Nickel-containing Steels at Sub-Zero Temperatures

R. W. NICHOLS: 'The Hardness of Some Carbon and Low-Alloy Steels at Low Temperatures.'

Jnl. Iron and Steel Inst., 1956, vol. 182, Apr., pp. 348-54.

Approximate ratios between the hardness of a steel and its ultimate tensile strength are well established for room-temperature conditions, but the validity of these relationships at sub-zero temperatures has not previously been fully studied. The variation, with applied load, of the diameter of impression made by a spherical indentor provides a measure of the capacity of a metal for strain-hardening, and such data, determined in room-temperature conditions, have been used to provide approximate stress-strain curves. The series of tests reported in this paper was made to determine the effect of low temperature on these relationships, in order to facilitate estimation of the low-temperature tensile properties of materials in circumstances which do not permit actual tensile tests. Tests were made, at 18°, −70° and −196°C., on the following materials:—0·3 per cent. carbon steel (as-rolled and in the annealed condition); 0·55 per cent. carbon steel, oil-quenched and tempered; 0·7 per cent. carbon steel, annealed; 2·5 per cent. nickel nickel-chromium and nickel-chromium-molybdenum steels, both oil-quenched and tempered, and a steel containing carbon 0·6, manganese 1·2, per cent., in the annealed condition.

It was found that throughout the tests the D.P.H. number was approximately proportional to the tensile stress at 8 per cent. strain, whereas the U.T.S./D.P.N. ratios for several of the steels were smaller at −196°C. than at the higher test temperatures. This difference was partially attributable to reduced initial rates of strain-hardening in these steels at the very low temperature, which were also revealed by lower Meyer indices obtained from ball-hardness tests in the same conditions. At all temperatures used stress-strain curves calculated from the ball-hardness results showed good agreement, over the range 4-8 per cent. strain, with comparable curves obtained directly in tension tests.

Mechanical Properties of Steels at Low Temperatures

See abstract on p. 147.

Corrosion by Hydrogen Sulphide at High Temperatures

See abstract on p. 148.

Electrolytic and Chemical Polishing Methods

See abstract on p. 122.

Low-Alloy Nickel-Chromium Case-Hardening Steel for Aircraft

MINISTRY OF SUPPLY: '$\frac{3}{4}$% Nickel-Chromium Case-Hardening Steel.'

D.T.D. Specification 5002, Mar., 1956.

The specification covers bars and billets for forging, bars for machining, forgings, and finished case-hardened parts, in steel of the following composition: carbon 0·13–0·18, silicon 0·10–0·35, manganese 0·6–1·0, nickel 0·6–1·0, chromium 0·4–0·8, molybdenum 0·10 max., sulphur 0·050 max., phosphorus 0·050 max., per cent. Heat-treatment, mechanical properties, and inspection and testing procedure are also laid down.

Metallurgy in the Nuclear-Power Field

See abstract on p. 139.

Steel Specifications: Ministry of Defence Grouping

MINISTRY OF DEFENCE: 'Steel Specifications (Grouping System).'

Defence Specification DEF-13, Jan. 1, 1953; reprinted Oct., 1955; 11 pp.

The group system covered by this schedule was developed to overcome difficulties experienced in obtaining supplies of steel to particular specifications. In it steels of similar mechanical characteristics are arranged in appropriate groups, permitting requirements to be met from a variety of existing specifications. The system is intended for use in obtaining steels for general engineering purposes, in cases in which mechanical properties are the paramount factor. Certain special applications falling outside the scope of its applicability are detailed. British Standard, Admiralty, and Ministry of Supply specifications which correspond to the respective groupings are correlated with them.

Notch Ductility of Carbon and Low-Alloy Steel Weld Metal

W. S. PELLINI: 'Notch Ductility of Weld Metal.'

Welding Jnl., 1956, vol. 35, May, pp. 217S–33S.

This 'interpretive report', sponsored by the Welding Research Council, is based on a critical consideration of authoritative information on the notch ductility of carbon and low-alloy steel weld metal. The data are culled from many published and unpublished sources and the review is supported by bibliographical references to literature and other information supplied to the Committee.

The scope of the report is shown below, by means of a list of the aspects considered:—

(1) The general significance of notch ductility, as related to the concepts of critical transition temperatures for the initiation and propagation of brittle fracture.

(2) The evaluation of the specific critical transition temperatures of various types of weld metal, and comparison with the critical transition temperatures of various types of base metal.

(3) The conditions which determine the path of propagation of fractures in weldments.

(4) The conditions which determine the point of initiation of fractures in weldments. This last item required detailed consideration of the case involving the presence of notch-like flaws and of that involving the absence of such flaws. Particular attention is directed, in both cases, to the rôle of weld metal notch ductility.

Properties of Brazed Joints in Nickel-Molybdenum Steel

G. HANSEL: 'Mechanical Properties of Butt Joints Brazed with BAg-1, BAg-3 and BCu Filler Metals.'

Welding Jnl., 1956, vol. 35, Apr., pp. 211S–16S.

The work recorded in this paper was carried out to establish data which would assist in selection of brazing conditions and filler metals suitable for production of joints in hardenable constructional steels. A steel containing nickel 2$\frac{1}{2}$, molybdenum $\frac{1}{2}$, per cent. was chosen as a representative parent material and the brazing alloys used were of the compositions shown in the table below.

Room-temperature impact, tensile and fatigue properties of joints prepared with these materials are recorded. The results obtained indicate that there is outstanding need for development of fluxes and of techniques which will consistently provide void-free joints.

Type	Ag %	Cu %	Zn %	Cd %	Ni %	Solidus		Liquidus	
						°F.	°C.	°F.	°C.
BAg-1	45·0	15·0	16·0	24·0	—	1125	607	1145	618
BAg-3	50·0	15·5	15·5	16·0	3·0	1193	645	1270	688
BCu	—	99·9	—	—	—	1982	1083	1982	1083

Photometric Determination of Nickel and Other Elements in Ferrous Materials

H. KOPP and E. ZINDEL: 'Photometric Analysis of Cast Iron and Steel.'

Giesserei, 1956, vol. 43, Apr. 26, pp. 210–16.

The authors urge the advantages of photometric analysis, and describe improvements in procedure which render such methods even more attractive for routine control purposes. In particular, the modifications described are advantageous in cutting down the time required for analysis, and they tend to simplification of procedure.

Full details are given of photometric determination of silicon, phosphorus, manganese, chromium, molybdenum, nickel and titanium, using the perchloric-acid procedure, and of estimation of nickel, cobalt, chromium, tungsten, molybdenum, vanadium, manganese and titanium in one master solution.

HEAT- AND CORROSION-RESISTING MATERIALS

Metallic Materials for Service at Temperatures above 1600°F. (870°C.)

AMER. SOC. TESTING MATERIALS: 'Symposium on Metallic Materials for Service at Temperatures above 1600°F.'

A.S.T.M. Special Tech. Publn. No. 174, published 1956; 193 pp.

Price: Members $2·65; Non-Members $3·50.

The publication contains the papers and discussions presented at the symposium held in June 1955 at Atlantic City, N.Y.

Certain of the papers were abstracted, in preprint form, at the time of presentation: in such cases a reference is given below to the abstract in *The Nickel Bulletin*. Papers not previously reviewed are now abstracted.

V. N. KRIVOBOK: 'Introduction', pp. 1–2.

Notes on the origin and scope of the symposium.

J. P. DENNY, L. P. JAHNKE, E. S. JONES and F. C. ROBERTSHAW: 'Some Sheet and Bucket Materials for Jet Engine Application at 1600°F. and Higher', pp. 3–15.

In certain conditions higher thrust can be obtained in jet engines by increase in operating temperature, but the availability of suitable materials for turbine-blade and sheet-metal parts is one of the factors limiting the extent to which advantage can be taken of this means of securing the additional thrust.

The paramount importance of blading material is emphasized by the author of this paper, with particular reference to the need for improved stress-rupture properties, fatigue-resistance, and impact strength. Oxidation-resistance may in most cases be expected to be satisfactory in materials which would come into consideration for such application; ability to resist thermal shock is a further requirement, ductility is significant, and the physical constants of the materials are important as affecting stress. Sheet-metal parts employed in the modern aircraft gas turbine occasionally encounter temperatures as high as 2100°F. (1150°C.) under low stress. High stress-rupture strength is of paramount importance: resistance to thermal shock, impact and fatigue is of less significance, as is density. Oxidation-resistance requires consideration, due to the potentially high operating temperatures.

The data assembled in this paper were prepared with a view to giving an all-over picture of the properties typical of representative materials of the highest grades now in commercial use for rotor blading and for sheet-metal components. Fabricating and welding characteristics are considered to be outside the scope of the review, but the materials discussed are types which are known to be successfully fabricated into gas-turbine components.

The turbine-blading materials for which properties are recorded are shown in the table below:—

Table I

Nominal Compositions of Rotor Blading Materials Tested

Material	C %	Cr %	Ni %	Co %	W %	Ti %	Mo %	Other Elements %
Haynes Alloy HE 1049 ..	0·4	26	10	45	15	—	—	B 0·4
Haynes Alloy No. 31 (X–40)	0·5	25	10	54	7·5	—	—	—
J–1570	0·2	20	30	39	6·5	4	—	—
0·3 per cent. niobium–molybdenum	—	—	—	—	—	—	99·7	Nb 0·3
0·5 per cent. titanium–molybdenum	—	—	—	—	—	0·5	99·5	—
K–162B Cermet			62% TiC + 8% (TaNbTi) C + 25% Ni + 5% Mo					

Four sheet materials are considered, of which the compositions are shown in Table II.

Table II

Nominal Compositions of Sheet Materials Tested

Material	C %	Cr %	Ni %	Co %	W %	Ti %	Mo %	Other Elements %
Incoloy T ..	0·10	20	34	—	—	1·0	—	Fe 44
Inco 702 ..	0·03	16	78	—	—	0·5	—	Al 3·5
Hastelloy Alloy C	0·10	16	55	—	4·5	—	17	Fe 5
Haynes Alloy No. 25 (L-605)	0·10	20	10	52	15	—	—	—

A series of tables and/or graphs gives information on the following properties for both groups of material: short-time tensile, stress-rupture, impact, fatigue. In most cases the data relate to temperatures well below and well above 1650°F. (898°C.); in many instances the upper limit at which properties were determined was 2000°F. (1093°C.). Some information on resistance to thermal shock is also given, and for some of the materials physical constants are tabulated (density, thermal expansion, thermal conductivity and modulus of elasticity). Structural and surface stability at temperatures above 1650°F. (898°C.) is discussed.

As a result of critical consideration of the characteristics of these 'high-calibre' materials, the following comments are made:—

Excellent nickel- and cobalt-base alloys are available for turbine blading up to at least 1600°F. (870°C.) and possibly to 1700°F. (925°C.), but it is unlikely that this group of materials will ever yield an alloy capable of operating at temperatures above 1800°F. (980°C.) unless stress levels are markedly reduced.

If means of protection against oxidation can be developed, molybdenum-base alloys would have a useful future in this field, since molybdenum has greater high-temperature stress-rupture strength than nickel-base or cobalt-base alloys or cermets.

Cermets offer promise for applications at temperatures up to about 1800°F. (980°C.), but beyond this, up to 2200° or 2300°F. (1205° or 1260°C.) some known molybdenum alloys show higher strength. Reduction in the metallic-binder content of cermets might give higher strength than that of molybdenum alloys at temperatures of the order of 3000°F. (1650°C.), but such modification would still further lower the resistance to impact, which is already a limitation with this class of material.

Sheet materials showing reasonably adequate strength and oxidation-resistance are available, if the necessary weight and price factors be admitted. The development of sheet materials having higher strengths in the range 1600°-2000°F. (870°-1095°C.) would, however, permit lighter-weight construction, which is an important consideration for the future. Although some improvement can be expected in this respect, it is considered relatively unlikely that sheet-metal alloys significantly stronger than the conventional types will be developed for use in that temperature range or above it. For high-stress applications involving the exposure of sheet metal to the temperatures above 1800°F. (980°C.) it will probably be necessary to resort to methods of cooling, to insulating coatings, or to the use of molybdenum-alloy sheet suitably protected against oxidation.

Although the possibility of employing air cooling in turbine blading or in fabricated sheet-metal parts is now under intensive study by many companies, such a method of overcoming existing difficulties would readily be abandoned if materials of adequate strength could be made available for operation at temperatures envisaged by modern jet-engine designers. Practical progress would appear likely only along the lines of close co-operation between designers and metallurgists.

W. E. BLATZ, E. E. REYNOLDS and W. W. DYRKACZ: 'Influence of Boron on Cast Cobalt-base S-816 Alloy', pp. 16-23.

See *Nickel Bulletin*, 1955, vol. 28, No. 9, p. 151.

W. BETTERIDGE and R. A. SMITH: 'Effect of Heat-Treatment and Structure upon Creep Properties of Nimonic Alloys between 750° and 950°C.', pp. 29-39.

See *Nickel Bulletin*, 1955, vol. 28, No. 9, p. 149.

S. S. MANSON and G. SUCCOP: 'Stress-Rupture Properties of Inconel 700 and Correlation on the Basis of Several Time-Temperature Parameters', pp. 40-6.

Inconel 700 is a nickel-base alloy of the following typical composition:—carbon 0·09, manganese 0·04, iron 0·46, sulphur 0·007, silicon 0·10, copper 0·02, nickel 46·51, chromium 14·82, aluminium 3·23, titanium 2·07, cobalt 29·42, molybdenum 3·21, per cent. The stress-rupture tests were made on material in the precipitation-hardened condition produced by solution treatment for two hours at 2150°F. (1175°C.), air-cooling, and tempering for four hours at 1600°F. (870°C.). The results are discussed in relation to comparable data published elsewhere on other alloys which are also of interest for use in the 1600°F. (870°C.) region, *viz.*, Inconel X, M-252,

S-816, cast X-40, a cast nickel-base alloy, and the titanium-carbide-base/nickel-alloy cermet, K.162B.

On the basis of extensive data on Inconel 700, in the stress range 5,000–130,000 p.s.i., the temperature range 1100°–2000°F. (593°–1093°C.) and the rupture-time range of 1–1,000 hours, it is concluded that this material shows promise for use at 1600°F. (870°C.) and possibly at higher temperatures. At 1600°F. (870°C.) it is considerably stronger than Inconel X, S-816 and M-252, and only slightly weaker than the nickel-base cast alloy and the cermet K.162B. The alloy has the advantage, *vis-à-vis* the cermet and the cast nickel alloy, of showing considerable ductility in the high-temperature range.

A. G. BUCKLIN and N. J. GRANT: 'Chromium-Nickel Alloys for High-Temperature Applications', pp. 47–56; disc. p. 56.

The paper covers a study of the properties of chromium-nickel alloys containing 35–70 per cent. of chromium, with 2–10 per cent. of iron, molybdenum, niobium and cobalt, in several combinations. The alloys were produced by precision casting, and were tested in stress-rupture at 1600°–1800°F. (870°–980°C.). It is shown that some of the alloys within this range of composition have properties equal to or better than those of forged S-816 for times longer than 1,000 hours at 1600° and 1700°F. (870° and 925°C.), and that they are also superior to that alloy after a 10-hour life at 1800°F. (980°C.). At the latter temperature they were found also to be better than nickel-base alloys hardened with aluminium+titanium. The hot-ductility characteristics of the alloys were 'more than adequate', although some evidence was found that with more than about 50 per cent. of chromium, in the presence of other body-centred-cubic alloying elements, the materials may be notch-sensitive, due to large amounts of the α chromium phase. At room temperature ductility in the as-cast condition was good, permitting a 20°–45° angle of bend, but the alloys embrittle both after ageing and after solution treatment+ageing.

The conclusion is reached that much additional study is required to produce further improvements in the properties of these alloys, both at room temperature and at 1600°–1800°F. (870°–980°C.). Vacuum melting is suggested as one means of attaining such improvement, and it is thought that the investigation of more complex systems, involving strengthening by carbon and by nitrogen, or by additions of aluminium and titanium, may prove fruitful.

J. E. BREEN and J. R. LANE: 'Effect of Rare-Earth Additions on the High-Temperature Properties of a Cobalt-base Alloy', pp. 57–65; disc., pp. 66–8.

See *Nickel Bulletin*, 1955, vol. 28, No. 10, p. 160.

F. VITOVEC and B. J. LAZAN: 'Creep, Rupture and Notch-Sensitivity Properties of S-816 Alloy up to 1650°F. under Fatigue and Static Stress', pp. 69–88; disc., p. 89.

At the University of Minnesota a study is being made of some of the basic factors which govern notch-sensitivity of materials under fatigue stress, and as a part of this investigation determination has been made of the fatigue and creep properties of several high-temperature materials, in both un-notched and notched form. The present paper reports a study of the alloy S-816, at temperatures up to 1650°F. (898°C.).

The composition of the material examined is given as carbon 0·397, silicon 0·50, manganese 1·12, chromium 19·42, nickel 20·02, molybdenum 4·1, sulphur 0·018, phosphorus 0·012, niobium 2·86, tungsten 4·03, iron 2·99, cobalt 42·9, tantalum 1·03, per cent.

Fatigue, stress-rupture and creep data, obtained under various stress conditions, are presented for temperatures of 75°, 1350°, 1500° and 1650°F. (25°, 735°, 815° and 898°C.). Tests were carried out under axial stress on un-notched specimens and on specimens having theoretical stress concentration factors of 2·4 and 3·4. The results are presented as *S-N* curves and stress-range diagrams, to show the effect of notch, temperature, ratio of alternating-to-mean stress, and magnitude of stress, on fatigue and creep properties. The significance of creep and fatigue as design factors, and the relation of notch-sensitivity to loading conditions are discussed, with particular reference to temperature and stress conditions.

K. PFAFFINGER, H. BLUMENTHAL and F. W. GLASER: 'Titanium-Carbide-base Cermets for High-Temperature Service', pp. 90–9; disc., pp. 99–102.

See *Nickel Bulletin*, 1955, vol. 28, No. 11, p. 191.

L. P. SKOLNICK and C. G. GOETZEL: 'Titanium-Carbide Products produced by the Infiltration Technique', pp. 103–9; disc., p. 110.

See *Nickel Bulletin*, 1955, vol. 28, No. 9, p. 152.

W. L. BRUCKART and R. I. JAFFEE: 'High-Temperature Properties of Molybdenum-Rich Alloy Compositions made by Powder-Metallurgy Methods', pp. 111–34.

The author briefly refers to the known advantages of molybdenum-base materials for use at high temperatures and to the major obstacle to full exploitation of their potential usefulness, *viz.*, their susceptibility to excessive oxidation at temperatures above about 900°F. (480°C.). Methods which are under study with a view to obviating this inherent limitation are indicated by reference to some of the major literature.

This paper is concerned with some molybdenum-base alloys and with a new type of molybdenum-base material in which substantial improvement in elevated-temperature strength is secured by dispersions of inert oxides or other non-metallic substances, in the molybdenum matrix. All the materials were prepared by the powder-metallurgy technique. Creep-rupture tests, at 1800°F. (980°C.), were made on

(1) binary molybdenum alloys containing aluminium, cobalt, chromium, iron, silicon, manganese and tungsten; (2) on ternary alloys of molybdenum with aluminium, chromium, silicon and tungsten and two ternary alloys containing boron; (3) on molybdenum-base materials containing small amounts of Al_2O_3, Cr_2O_3, SiO_2, TiO_2 and ZrO_2. Data from tests at 2000°F. (1093°C.), on molybdenum containing 0·1 per cent. ZrO_2, are also presented. Illustrations of typical molybdenum/oxide compositions are shown.

Among the principal conclusions drawn from the tests are the following:—of the addition elements studied, silicon, chromium, aluminium and tungsten are the most effective in increasing creep life at 1800°F. (980°C.). The best creep properties were obtained in an alloy containing 0·19 per cent. of silicon: this material had a life of 292·7 hours at that temperature under 25,000 p.s.i. (11·15 tons per sq. in.). Boron additions proved detrimental to creep life.

Nickel cladding was shown to protect molybdenum at the temperature of test, and to have no effect on creep life. The presence of the cladding usually limited total elongation to 7-9 per cent.

A major indication from these tests is that dispersions of oxides, and probably of non-metallics in general, in molybdenum, confer major increases in creep life at 1800°F. (980°C.). Such improvement is secured without sacrifice of room-temperature properties. Among the oxides studied, the most effective proved to be the hard, stable oxides of the transition metals, ZrO_2, TiO_2 and Cr_2O_3. It is considered that the study of the oxide-containing materials, and of the influence of particle size, of alloying elements in conjunction with dispersions, etc., offers a promising field of investigation.

E. D. WARD and W. G. TALLIS: 'Tension and Torsion Tests on Nimonic Alloys at High Temperatures', pp. 135-45.

See *Nickel Bulletin*, 1955, vol. 28, No. 9, p. 150.

H. E. LARDGE: 'Thermal-Fatigue Testing of Sheet Metal', pp. 146-59; disc., pp. 160-3.

The author reports methods devised for study of thermal fatigue in sheet metal, developed with special reference to investigations on flame tubes in aircraft gas turbines. The test is based on heating a specimen having a central hole, to 1650°F. (898°C.), and cooling it rapidly in a blast of cold air. These conditions were related as closely as possible to those existing in typical flame tubes during acceleration, and deceleration conditions, when a maximum drop of 800°F. (445°C.) may occur in about 2·5 seconds, with 90 per cent. of the change taking place in one second. The test apparatus is described and illustrated, and its use is demonstrated by a report of tests on (1) high-temperature materials, including Nimonic alloys, Inconel, austenitic and duplex-structure nickel-chromium stainless steels, and ferritic high-chromium steels; (2) mild and low-alloy steels; and (3) laminated material in the form of copper clad on both sides with Nimonic 75 alloy. In addition, the same method has been used for assessment of the thermal-fatigue resistance of some ceramic coatings and other protective finishes.

The data recorded indicate that the test serves as a useful guide in selection of materials for manufacture of gas-turbine components and other high-temperature sheet-metal parts. One of the variables considered in the paper is the influence of thickness of sheet on thermal-fatigue resistance.

T. A. HUNTER: 'Thermal-Shock Testing of High-Temperature Metallic Materials', pp. 164-79; disc., pp. 180-2.

This paper is concerned with work done at the Wright Air Development Center, with specific relation to materials used for gas-turbine blading. The aim of the tests was three-fold: (1) development of a reliable thermal-shock apparatus, using compressed air as the coolant, (2) devising of a reasonably reproducible test, including a satisfactory definition of thermal-shock failure, and (3) assessment of the relative thermal-shock resistance of various high-temperature materials falling within the groups used for gas-turbine rotor blading.

The test devised employs a cycle involving electrical-resistance heating, followed by a cold-air-blast shock-cooling cycle, reproducing fairly closely changes occurring in a gas turbine during extreme conditions. An illustrated description of the test rig and test procedure is given.

The materials tested were of five types:—

Cermets (two of unspecified compositions).

Iron-base materials (three austenitic stainless steels and N-155 alloy).

Nickel-base alloys (Waspalloy, Hastelloy C, Inconel, Nimonic 80A, M-252).

Cobalt-base alloys (cast HS 21, cast S-816 and wrought S-816.)

A special chromium-rich alloy, Battellalloy, the composition of which is not detailed.

The average number of thermal-shock cycles to failure for each material is tabulated, for maximum temperatures of 1600°, 1700°, 1800°, 1900° and 2000°F. (870°, 925°, 980°, 1035° and 1093°C.), respectively. The chromium-rich alloy Battellalloy showed outstandingly good resistance. Of the other materials, only three, M-252, N-155 and cast S-816, had a thermal-shock resistance of over 1,000 cycles when tested at 2000°F. (1093°C.). In tests in which cycling was from 1600°F. (870°C.), the lowest upper temperature used, thermal-shock resistance values ranged from 3,002 cycles for a niobium-stabilized austenitic nickel-chromium steel to 18,000 cycles for cast S-816. Tests made on two specimens of Inconel showed a degree of scatter which demonstrates that wide variation in properties is to be expected in reputedly identical material.

In all the materials tested, raising of the upper temperature of the test cycle lowered the thermal-shock resistance: in some alloys, e.g., Waspalloy and cast S-816, such loss of resistance was especially severe above 1600°F. (870°C.).

The investigation revealed no example of cracking

from a single thermal shock, indicating that the action is gradual and cumulative, and that the failure process thus becomes a combination of fatigue and stress-concentration effects.

Mechanical cold-stretching of Inconel prior to thermal-shock testing caused no significant change in resistance to thermal fatigue, and thermal heating and cooling under non-shock conditions had a negligible effect on the thermal-shock resistance of S-816. Tests of the influence of the coolant used in the 2000°F. (1093°C.) tests on Inconel showed little difference between the thermal-shock resistance of specimens cooled by air and those cooled by helium.

A. BLAINEY: 'The Development of Zirconium-Rich Protective Coatings and Brazing Materials for Heat-Resisting Alloys', pp. 183–93.

Heat-resisting alloys of the nickel-chromium types and high-alloy austenitic steels are finding increasing application for construction of dies used in the hot forming of metal powders and in other applications in which there is contact with moving metals at high temperatures. Although the mechanical strength of such materials is frequently sufficiently high at the service temperatures, they are liable to suffer from surface erosion. Various methods have been devised for lessening this effect, e.g., pre-forming of suitable adherent oxide films on the dies, or the use of lubricants such as graphite, but known methods have inherent limitations, and research is being directed towards development of alloy coatings which will give improved resistance to high-temperature erosive conditions. Practical considerations dictate that the mode of application of the alloy coating should be as simple as possible, e.g., mechanical application followed by diffusion into the surface of the basis material. In the present paper the use of this method for production of zirconium-alloy coatings is described, and a report is made of oxidation and other tests carried out on materials so coated.

The method adopted for application of the coatings involves cleaning the basis material, followed by application of a layer of zirconium powder (0·002–0·010 in. thick) by brushing or by spraying a suspension of the powder in a suitable liquid. The coated metal is then dried and is heated to a temperature of 1740°–2100°F. (950°–1150°C.), in hydrogen or preferably in vacuo, to form a molten alloy of the powder and the base metal, so creating an impervious well-bonded coating of zirconium-rich alloy. The influence of processing variables (surface condition of the base metal, purity and particle size of powder, method of preparation of the powder, type of suspension fluid, etc.) was studied, and the effects producible by addition of other elements to the powder coating were also considered.

Since the experiments were designed specifically to develop coatings which would give protection of heat-resisting alloys against erosion by metals during hot-pressing and extrusion, tests were carried out (1) with uranium, contact with which metal sets up particularly severe conditions (due to formation of low-melting-point eutectics with constituents of the nickel-chromium alloys), and (2) with magnesium/magnesium-oxide cermets, which erode nickel-chromium alloys. Conditions of test were arranged to simulate both die operation and extrusion, and zirconium-rich alloys of various types, as well as unalloyed zirconium, were used as the initial material for the coatings.

The results demonstrated the feasibility of producing satisfactory coatings by the method described, showing that protection can be secured against erosion by uranium at 1560°F. (850°C.) and by magnesium/magnesium-oxide mixtures at 1110°F. (600°C.). The hardness of the coatings can be increased by suitable alloying additions (e.g., tungsten, chromium, aluminium, lead), and by appropriate heat-treatment. Resistance of the coatings to oxidation in air at high temperatures is inferior to that of nickel-chromium alloys, but this is not a matter of primary importance in the case of die protection, where non-oxidizing conditions usually obtain, nor in inert or reducing conditions, such as occur in certain liquid metals.

Zirconium-rich alloys were found also to show promise as brazing materials for heat-resisting alloys such as Nimonic 75. The shear strength of strip in this alloy brazed at 2100°F. (1150°C.) with a mixture of zirconium powder and 1 per cent. tungsten powder was 33,700 p.s.i. (15 tons per sq. in.) at 1690°F. (920°C.) and 13,400 p.s.i. (6 tons per sq. in.) at 2010°F. (1098°C.). The warning is given, however, that atmospheric oxidation may be a serious factor limiting the possible use of such joints in air or other reactive gases, unless an oxidation-resistant layer can be formed over the zirconium alloys, for example by deposition of silicon and subsequent reaction to form zirconium silicide.

Creep/Rupture Relationships in High-Temperature Alloys

F. C. MONKMAN and N. J. GRANT: 'An Empirical Relationship between Rupture Life and Minimum Creep Rate in Creep-Rupture Tests.'

Amer. Soc. Testing Materials, Preprint 72, June 1956; 13 pp.

Tests on a wide range of alloys based on aluminium, titanium, nickel or cobalt, and on stainless steels of both the ferritic and austenitic types, have demonstrated that, for a large number of alloys, an empirical relationship exists between rupture life and minimum (secondary) creep rate. The establishment of such a relationship would make possible estimation of rupture life from the minimum creep rate determination in an individual creep-rupture test.

The nickel-base alloys included in the tests were of the following types:—

M-252	Precipitation - hardening nickel - chromium-molybdenum alloy containing aluminium and titanium.
Nimonic 80	Precipitation - hardening nickel - chromium alloy containing aluminium and titanium.

Nimonic 90, INCO 700 { Precipitation hardening nickel-chromium-cobalt alloys containing aluminium and titanium.

S-816 and S-590 were the materials representative of cobalt-base alloys.

The effects of variables such as testing stress, temperature, composition, and total ductility were studied in relation to their influence on the empirical relationship.

Constitution of the Ni_3Al Phase of Nickel-Aluminium Alloys

E. M. GRALA: 'Investigation of the Ni_3Al Phase of Nickel-Aluminium Alloys.'

Nat. Advisory Committee for Aeronautics, Tech. Note 3660, Apr., 1956; 24 pp.

Many intermetallic compounds, such as NiAl and Ni_3Al, are of interest for high-temperature applications because they have high melting points and are stable at elevated temperatures. The author had previously discussed these two compounds, on the basis of properties obtained from as-cast specimens, which were cored and also contained a secondary structure.

In this later research a study was made of the properties of two compositions within the Ni_3Al range, before and after homogenization. The materials used contained, respectively, 13·3 and 14·0 per cent. aluminium by weight. The 13·3 per cent. aluminium alloy showed an average as-cast room-temperature tensile strength of 28,600 p.s.i. (12·75 tons per sq. in.), with 1·0 per cent. elongation. After homogenization at 1800°F. (982°C.) the room-temperature tensile strength fell to 20,350 p.s.i. (9·0 tons per sq. in.), with 0·2 per cent. elongation. The 14 per cent. aluminium alloy had better tensile properties. The average as-cast room-temperature tensile strength was 39,250 p.s.i. (17·5 tons per sq. in.), and the strength after homogenization was 32,100 p.s.i. (14·35 tons per sq. in.). At 1500°F. (815°C.) the average tensile strength for the latter alloy was 19,600 p.s.i. (8·75 tons per sq. in.). The 13·3 per cent. aluminium alloy was not hot-workable: it showed moderate impact strength. Stress rupture was evaluated for the 14 per cent. aluminium alloy at 1500°, 1600° and 1700°C. (815°, 870° and 926°C.).

Notch-Tensile Characteristics of Nickel-containing Materials

See abstract on p. 122.

Metallurgy in the Nuclear-Power Field: Symposium

AMER. INST. MINING AND METALLURGICAL ENGINEERS, INST. METALS DIV.: 'Nuclear Metallurgy. A Symposium on Behaviour of Materials in Reactor Environment.' *A.I.M.E., IMD Special Report Series* No. 2; 94 pp. Published by the Institute, 1956.

This symposium, held in February, 1956, was organized with a view to providing practically useful information to the metallurgical public not associated with atomic-energy work. The primary aim was to describe the peculiar problems and fields of application of commercial metallurgical materials in various reactor environments. The scope of the individual papers is indicated below:—

R. C. DALZELL: 'General Problems in the Application of Materials in Reactor Environments', pp. 1-3.

A condensed introductory review of basic conditions in reactors and of operating factors which will dictate selection of materials of construction.

D. H. GURINSKY: 'The Behaviour of Materials in Aggressive Liquid Metals', pp. 5-20.

An aggressive liquid metal is defined, for the purpose of this paper, as one which attacks the common metallic materials of construction moderately to severely at temperatures of the order of 1000°F. (540°C.), under dynamic conditions. For information on attack by very aggressive metals (zinc, tin, aluminium, etc.) reference is directed to the Liquid Metals Handbook. The present paper deals with corrosion by mercury, and by molten lead and bismuth, which are considered as a group, since the attack which they impose can be explained as resulting primarily from the solubility (or, more correctly, from the temperature coefficient of solubility) of the materials of construction.

Information available to date is correlated, and attention is directed to the following points, in summary of the known facts:—

'In static tests the attack of iron-base alloys with low nickel content is slight in lead and mercury at temperatures of the order of 1000°F. (540°C.), because of the very low solubility of iron, whereas the attack is moderate to severe in bismuth, where the solubility of iron is a hundred-fold greater than in the other two liquids. In applications where any of the three liquids is to be used in a dynamic system in which a temperature gradient exists, the temperature coefficient of solubility, as well as the absolute solubility, is of importance in determining the intensity of the attack. Iron alloys cannot be used as construction materials for such systems because mass transfer and plugging takes place unless inhibitors are added to the liquid metal. Such additions have been demonstrated as being effective for mercury and bismuth. It is believed that further work may show that mass transfer in lead at elevated temperatures can also be minimized by similar treatment.'

E. G. BRUSH and R. F. KOENIG: 'Behaviour of Materials in Non-Aggressive Liquid Metals', pp. 21-32.

This paper concerns the behaviour of various metals and alloys in contact with liquid sodium and sodium-potassium alloys. These two types of material offer a good compromise among the liquid metals which can be considered as heat-transfer media, since they possess adequate capacity for pumping, low melting points, and relatively low cross section for thermal neutron capture, and they cause relatively low corrosion attack, by comparison with other liquid metals and alloys. They are also readily

available in adequate quantities. Reference is made to two operating reactors in the U.S.A. which are using sodium or sodium-potassium alloy.

In this paper some difficulties involved in using these media are discussed, with a consideration of metallurgical and operational problems, and corrosion. The latter aspect is discussed at some length, as relating to mass transfer and preferential attack arising from the widely varying solubilities of individual metals in sodium. The significance of impurities present in the liquid metals, as affecting corrosion attack, is emphasized.

The later part of the paper reports evaluation of the behaviour of a wide range of materials in contact with liquid sodium and sodium-potassium, based on observations made in two power-producing nuclear plants, in pilot-plant heat-transfer systems, and in laboratory tests. A chart shows the general usefulness of the respective materials in the liquid metals at various temperatures, and the data obtained in the various tests are critically discussed. A few of the outstanding comments are recorded below.

'*Ferrous Materials*

Carbon and low-alloy steels show promise of satisfactory resistance to mass transport in sodium and sodium-potassium up to 1000°F. (540°C.), but further work is required to determine the purity (oxygen level) below which neither mass transport nor decarburization is significant. Carbon steels, and probably also low-alloy steels, are, however, subject to diffusion bonding, but this disadvantage can be overcome by correct design. The usefulness of ferritic alloy steels above 1000°F. (540°C.) will be mainly dependent on requirements for mechanical strength, but it must also be recognized that the tendency of these steels towards mass transport increases rapidly above that temperature.

'Austenitic stainless steels, particularly the niobium-stabilized '18–8' type, have been the materials mainly used in sodium and sodium-potassium systems. They have proved completely resistant to attack up to 1000°F. (540°C.) in sodium containing less than 0·005 per cent. of oxygen in large-scale heat-transfer equipment and in nuclear power plants. Straight 18–8 chromium-nickel steel is also corrosion-resistant in these conditions. Austenitic stainless steels have also been tested in heat-transfer equipment at temperatures up to 1500°F. (815°C.).

'No mass-transport difficulty has been observed up to 1200°F. (650°C.), although carburization from carbon contamination in sodium proceeds rapidly and may impose very low limits on carbonaceous impurities. At 1300°F. (705°C.) diffusion bonding becomes a problem, and at 1500°F. (815°C.) severe mass transport has been observed. These observations emphasize the importance of maintaining high purity in the system.

'*Nickel Alloys*

Up to 1000°F. (540°C.) nickel and nickel-base alloys are approximately as resistant to attack by sodium and sodium-potassium as are the austenitic stainless steels. They are, however, very sensitive to attack by oxygen-contaminated sodium, especially at relatively high temperatures. The mass-transport tendency of nickel alloys becomes significant at about 1500°F. (815°C.): the effect is markedly influenced by minute amounts of oxide contamination. No advantage, except that of strength, is gained by using highly alloyed ferrous and cobalt-base high-temperature alloys in sodium and sodium-potassium: their resistance to corrosion is approximately equivalent to that of the austenitic steels.

'*Copper-base Materials*

The common copper-base alloys are susceptible to preferential attack in sodium and sodium-potassium, and copper shows extensive mass transport in sodium at temperatures above 600°F. (315°C.).

'*Cermets*

Cobalt- or nickel-bound tungsten-carbide, titanium-carbide, and chromium-carbide cermets show excellent resistance to attack in sodium up to 1000°F. (540°C.) in dynamic systems. The indication, from static test data, is that these materials are also satisfactory at higher temperatures, but further tests are necessary before selecting them for specific applications.

'*Brazing Alloys*

With the exception of materials containing large amounts of copper, phosphorus, or silver, most high-temperature brazing alloys show good resistance to sodium up to 1000°F. (540°C.), but their resistance to attack at higher temperatures varies considerably, and no general recommendation can be made.

'*Ceramic Materials*

Many ceramics, such as alumina, magnesia, titania, etc., are unaffected by exposure to sodium, whereas others, such as silica and boric oxide, are readily attacked. Difficulties encountered with ceramics which are thermodynamically stable in sodium arise from the porosity of compacted ceramics and from the attack of silicate-type binders.'

J. E. DRALEY and S. GREENBERG: 'The Application of Materials in Low-Temperature Water and Organic-Liquid-Cooled Reactors', pp. 33–53.

The various aspects of the subject are discussed first from the point of view of a low-temperature light-water-cooled reactor: later, attention is given to additional factors which must be considered in using heavy water and organic materials as coolants. The respective sections of the paper deal with:—

(1) *Fuels and source materials* (uranium and high-uranium alloys, thorium and high-thorium alloys, plutonium),

(2) *Control materials used to absorb thermal neutrons*, in order to maintain the nuclear process at the desired rate or to stop it (solid elements in rod form, or liquid media),

(3) *Cladding*, to protect the fuel, producer and control-rod materials against corrosion by the

coolant. It should also prevent escape of fission products and other radioactive material into the coolant stream,

(4) *Structural and control-system materials* (including piping, reactor vessels, heat exchangers, pumps, control systems other than control rods).

(5) *Moderators used to decrease the energy of neutrons* (with particular reference to graphite and beryllium and its compounds).

(6) *Shielding*, covering materials and methods used to reduce the levels of nuclear radiation at the outside of the shield to biologically acceptable levels.

(7) *Coolants* (maintenance of purity of light water; effect of radiation and induced radioactivity; additional problems involved in use of heavy water; advantages and limitations of organic coolants).

The paper includes various references to the use of nickel-containing materials, e.g., in control rods, for which a boron-containing stainless steel has been found suitable, and in reactor tanks and other components. Attention is directed also to the value of a small addition of nickel (about 0·5 per cent.) to aluminium alloys used for cladding. At temperatures above about 200°C. local penetration and damage of aluminium-base materials occurs in distilled water, and prevention of this type of attack is important if successful functioning is to be ensured. Such attack can be prevented by alloying with metals characterized by low hydrogen overvoltage: alloys containing more than 0·5 per cent. of nickel are immune from such deterioration in distilled water at temperatures up to 350°C. (For further details see paper by the same author referred to on p. 145 of this issue of *The Nickel Bulletin*.)

Nickel-containing Materials in Nuclear-Power Plant

UNITED NATIONS: 'Proceedings of the International Conference on the Peaceful Uses of Atomic Energy. Vol. 9. Reactor Technology and Chemical Processing.' Published by *United Nations, New York*, 1956; 771 pp. Price 70/-.

The sessions and subjects covered by the material contained in this volume are shown below:—

Session	*Subjects*
7.3	Waste Disposal Problems.
18B.1	Metallurgy of Thorium, Uranium and their Alloys.
18B.2	Fabrication of Fuel Elements.
19B.1	Handling Liquid Metals.
19B.2	Liquid Metal Heat Transfer.
20B	Chemical Aspects of Nuclear Reactors.
21B	Chemical Processing of Irradiated Fuel Elements.
22B.1	Chemical Processing of Irradiated Fuel Elements (concluded).
22B.2	Separation and Storage of Fission Products.
23B.1	Disposal in the Ground.
23B.2	Disposal in the Sea.
23B.3	Airborne Problems.

A number of papers contributed to these sessions include data which are of interest in relation to the uses of nickel-containing materials in nuclear-power plant. Brief notes on some of the references are given below. It should be emphasized that in many cases the allusions to nickel and its alloys are incidental, in the course of major discussions of aspects other than that of materials of construction.

O. N. CARLSON *et al.*: 'The Metallurgy of Thorium and its Alloys', pp. 74–106.

The material contained in this comprehensive paper has been selected from a large amount of data obtained by many investigators. It represents the present state of knowledge on the metallurgy of thorium and its alloys. Sections of the review deal, respectively, with the occurrence of thorium and processing of monazite, preparation of thorium metal by various processes, physical and thermodynamic properties of thorium, melting and casting, heat-treatment and recrystallization, fabrication, mechanical properties, corrosion of thorium and twenty-one types of thorium alloy, metallography, thirty-five thorium alloy systems (including thorium-nickel), and hazards associated with processing and use of thorium.

The diagram of the thorium-nickel system given in the paper is based on the work of Horn and Bassermann (*Zeitsch. f. Metallkunde*, 1948, vol. 39, p. 272), revised to bring it into agreement with the crystallographic data reported by FLORIO *et al.* (*Acta Crystallographica*, 1956, vol. 9, p. 367–72.) Both investigations have shown the presence of five intermediate phases, all of which are compounds, generally isomorphous with corresponding compounds in the thorium-cobalt and thorium-iron systems.

A. S. COFFINBERRY and F. H. ELLINGER: 'The Intermetallic Compounds of Plutonium', pp. 138–46.

A compilation of X-ray diffraction and crystal-structure data for numerous binary compounds of plutonium, including $PuNi_5$ and Pu_2Ni_{17}.

C. E. WEBER and H. H. HIRSCH: 'Dispersion-Type Fuel Elements', pp. 196–202.

Dispersion-type fuel elements are defined as elements in which the fuel is heterogeneous, consisting of a fissile phase dispersed in a continuous matrix of non-fissile material. In this paper the non-fissile material is limited to a pure metal or alloy: the relative merits of nickel and other metals for this purpose are discussed. The effects of radiation from fissile components, on the mechanical properties of the matrix material, are illustrated by data on hardening observed in a UO_2-stainless steel element.

A. H. BARNES: 'Pumping of Liquid Metals', pp. 259–64.

Increasing interest in liquid metals as reactor

coolants has made necessary the development of pumps which are capable of circulating such liquids at elevated temperatures for prolonged periods. Design is governed not only by the chemical activity of the materials handled but also by the fact that they may be highly radioactive, necessitating the use of pumps free of all risk of leakage and requiring essentially no maintenance. This article describes representative units of the following types:—mechanical, electromagnetic, alternating-current-conduction and alternating-current induction. Materials of construction employed in such pumps include stainless nickel-chromium steels of various grades, and 80-20 nickel-chromium alloy, selected on the dual basis of compatibility with sodium and sodium-potassium alloy and suitability of electrical properties.

C. B. JACKSON and R. C. WERNER: 'The Use of High-Temperature Sodium in Manufacture of NaK Alloy', pp. 270-2.

The authors describe equipment and operating procedure used in batch and continuous processes for production of potassium and sodium-potassium alloy, and also discuss the handling of these substances at high temperatures.

The process initially developed was a batch reaction of sodium with potassium chloride, to produce a sodium-potassium mixture which was fractionally distilled to obtain pure potassium, and later development of a continuous process increased output and reduced costs. The authors emphasize the importance of correct choice of materials for equipment used in both processes. Molybdenum-containing stainless 17-12 chromium-nickel steel has been found more satisfactory than the molybdenum-free austenitic steels for most purposes, and a 25-20 chromium-nickel type has given good service in salt-melt pots, being highly resistant to flameside oxidation.

J. R. WEEKS *et al.*: 'Corrosion Problems with Bismuth-Uranium Fuels', pp. 341-55.

In a design for a liquid-metal reactor under investigation at the Brookhaven National Laboratory, U.S.A., the fuel selected is a solution of uranium dissolved in bismuth. The blanket or fertile material is a dispersion of an intermediate compound of thorium and bismuth in bismuth. Graphite is being considered as the moderator for the core and blanket.

The choice of these materials and of the materials of construction for the equipment handling them has given rise to various corrosion problems, and the results of a study of some of these difficulties are given in the present paper. The following aspects are considered:—(1) the reaction of uranium with graphite; (2) the stability of liquid-metal fuel with respect to container materials other than graphite; (3) corrosion and mass transfer of iron and chromium by liquid bismuth; (4) fundamental problems of corrosion, as affecting corrosion by the fuels involved. In section (2) a study was made, *inter alia*, of the influence of iron, chromium, nickel, magnesium and zirconium, on the solubility of uranium in bismuth. The presence of nickel caused a large decrease in the solubility, at various temperatures. Reference is also made to work by other investigators, in which it had been shown that corrosion and mass transfer by liquid bismuth in steel containers was intensified by the presence, in the bismuth, of a number of metallic additives, but that aluminium, chromium, nickel, titanium and zirconium had the reverse effect. Titanium and zirconium were the most beneficial in this respect. It is noted that low-alloy and low-carbon steels showed markedly better resistance than austenitic nickel-chromium steel to liquid bismuth, and that reduction in the corrosion rate of a 5 per cent. chromium steel by bismuth could be effected by addition, to the liquid metal, of trace amounts of titanium and magnesium.

R. A. BAUS *et al.*: 'The Solubility of Structural Materials in Sodium', pp. 356-63.

The paper includes experimental data relating to the solubility of iron in sodium and sodium saturated with oxygen, the solubility of niobium-stabilized 18-8 chromium-nickel steel in sodium, and the deposition of component elements of this steel from liquid sodium. Penetration of radioactivity in the austenitic steel, the rate at which it is attacked by sodium at elevated temperatures, and the rate of saturation of sodium with components of the steel were also investigated. Attention is directed to the significance, in reactor service, of tantalum and cobalt, present as impurities in the stainless steel.

J. E. DRALEY and W. E. RUTHER: 'Aqueous Corrosion of Aluminium Alloys at Elevated Temperatures', pp. 391-6.

This paper contains basic information on the corrosion of aluminium in distilled water at normal temperature, to serve as a background to a detailed report on corrosion attack undergone by this material at temperatures above 200°C.

At the higher temperatures, aluminium and a number of aluminium-base alloys appear to undergo 'normal' corrosion for some time and subsequently develop characteristic blistering, which is believed to originate at stringers and at grain boundaries. At high temperatures the attack occurs quite rapidly: in some cases specimens have completely disintegrated to an oxide corrosion product in four hours' exposure in distilled water at 315°C. The onset and rate of attack have been found to vary with the composition of the aluminium-base material, the mechanical treatment which the material had previously undergone, and the pH of the water. Blistering and disintegration can be retarded to a marked extent by passage of an electric current through the sample, to make it more anodic. An explanation of the mechanism of the attack is advanced by the authors.

In considering methods which may be adopted to minimize blistering, it was found, *inter alia*, that addition of a small amount of nickel had a highly beneficial effect. Aluminium-nickel alloys in which

the nickel-rich constituent appears as a second phase largely segregated at the grain boundaries showed excellent resistance to blistering. Addition of silicon to a 1 per cent. nickel alloy made from high-purity aluminium indicate that more than 0·1 per cent. of silicon causes rapid failure by blistering, whereas addition of 0·2–1 per cent. of iron to a similar aluminium-nickel alloy proved beneficial.

D. E. THOMAS: 'Aqueous Corrosion of Zirconium and its Alloys at Elevated Temperatures', pp. 407–13.

High-temperature water-cooled and moderated thermal reactors require, for the core, a structural material which is corrosion-resistant and which has a low thermal neutron capture cross section. Conventional structural materials are unsuitable.

The properties of zirconium (low thermal neutron cross section and good resistance to corrosion by high-temperature water) render it promising for use as a core, but it has been found that achievement of maximum corrosion-resistance is dependent on close control of certain impurities in the metal and that resistance to attack can be still further enhanced by suitable alloying. This paper records evidence on these two aspects, giving data on the behaviour of zirconium in high-temperature water and in steam, and a report of tests on a wide range of binary and some ternary zirconium-base alloys.

In the binary series principal attention was given to alloys containing small amounts of tin, iron, nickel or chromium. Tin proved beneficial, promoting adherence of the corrosion product and tending to counteract the harmful influence of nitrogen. Small additions of iron, chromium or nickel (of the order of 0·1 per cent.) improved corrosion-resistance: raising the alloy content from 0·1 to 0·5 per cent. made little difference, and the presence of more than 0·5 per cent. of these elements resulted in decreased resistance to attack by high-temperature water, but improved the behaviour in steam at 400°–816°C.

In the ternary series, small amounts of iron, nickel or chromium were found to have a very beneficial effect on the corrosion-resistance of zirconium-tin alloys: approximately 0·25 per cent. of the third element was required to achieve maximum resistance, and it was observed that nickel and iron were more effective than chromium. No other third element was so potent as this group. The improvement was found in both high-temperature water and in steam.

The introduction of Zircaloy 2 (containing 1·5 per cent. of tin with small amounts of iron, chromium and nickel) has made possible use of zirconium sponge produced by the Kroll process. The corrosion-resisting properties of this type of alloy, which are described in the paper, are relatively insensitive to heat-treatment, and, within reasonable limits, to the concentration of the alloying elements. The amount of nitrogen which can be tolerated depends upon the severity of the conditions in which the alloy is used: oxygen has a negligible influence on corrosion-resistance. Aluminium, lead, silicon, copper and manganese require to be controlled, but exact information on permissible limits has not yet been established.

A. S. KITZES and R. N. LYON: 'Aqueous Uranium and Thorium Slurries', pp. 414–22.

Uranium slurries as homogeneous reactor fuels have some significant advantages over solutions, e.g., they are less corrosive. There is currently much interest in the use of uranium oxide slurries, for this purpose, and of the thorium compounds which might be used, thorium oxide appears most promising. These two compounds are the subject of this paper.

The authors discuss the chemical stability of uranium oxide (UO_3) slurries at elevated temperatures, preparation of UO_3H_2O slurries, and the characteristics of such mixtures. Tests in which uranium-trioxide slurries were circulated under a variety of conditions, for thousands of hours, showed that attack of stainless-steel components by such slurries at 250°C. is essentially nil, even on pump impellers having a tip velocity of 120 feet per second. Some trouble was experienced with caking of the slurry on the pipe walls, but this was greatly reduced by the use of suitable additives.

The characteristics of thorium oxide and its action at elevated temperatures were found to differ widely from those of uranium oxide. The erosive-corrosive attack of the former, when used at high velocity in contact with stainless steel, proved to be many times greater than that of uranium oxide. Tests on fifteen corrosion- and/or wear-resisting materials (including Inconel and stainless steels) indicated that materials which form a strongly adherent protective oxide film are more resistant to attack by ThO_2 slurries than are materials which are chemically more inert. The degree to which such slurries attack stainless steel is a function of the method by which the slurry is manufactured; it is affected also by its pH and the reduction potential.

T. ROCKWELL and P. COHEN: 'Pressurized Water Reactor (P.W.R.) Water Chemistry', pp. 423–35.

When consideration was first given to construction of large pressurized water reactors it was believed that the technology of handling water at 400°–600°F. (205°–315°C.) in austenitic stainless-steel equipment was relatively well understood, but application of existing knowledge to reactor systems has given rise to a number of difficulties. This paper discusses the problems encountered, steps which have been taken (under the auspices of the U.S. Atomic Energy Commission) to investigate them, and the current stage of progress in this branch of technology.

It is concluded that normal corrosion, in the absence of radiation, can be satisfactorily accommodated with commercially available materials, and the indication to date is that although radiation tends to increase the rate of corrosion of metals in water, this can be without practical significance, as the materials concerned produce tightly adhesive corrosion

films. Tests reported in the paper confirm this conclusion.

Laboratory investigations have included a study of the effect of radiation on water chemistry and on typical conventional boiler-water additives, radioactivation of water, fouling of heat-transfer surfaces, effect of water chemistry on friction of rubbing surfaces. A detailed description is also given of techniques employed in development of water technology, and a brief report is made of problems encountered during attempts to substitute carbon steel for stainless steel in various components of pressurized water reactors.

The final section of the paper is concerned with the design and operation of full-scale plant in which laboratory principles are applied. Individual sections of the review deal with cleanliness and pre-conditioning of material and components; treatment of feedwater; corrosion inhibitors; purification in side streams; sintered stainless-steel filters; ion-exchange procedure; methods of analysing coolants; dissolved gases, etc.

D. J. FERRETT and G. W. C. MILNER: 'Applications of Square-Wave Polarography to Analytical Problems from Experimental Reactor Loops', pp. 436–40.

The application of square-wave polarography to determination of very low concentrations of metal ions is discussed. By the procedure described, nickel at levels down to 0·4 p.p.m. can be estimated.

F. L. CULLER: 'Re-Processing of Reactor Fuel and Blanket Materials by Solvent Extraction', pp. 464–83.

A comprehensive survey of the technology of re-processing irradiated fuel elements by solvent extraction, condensed from results obtained by the work of many investigators in the U.S.A., Great Britain and Canada, and embodied in numerous individual reports. Chemical flowsheets of the various processes are presented and the more important variations in chemical and engineering processing are considered. In discussing equipment, emphasis is laid on the importance of using stainless steel for all parts inside the processing cells and in various other parts of the installations.

D. O. CAMPBELL: 'Removal of Fission Products from Stainless Steel', pp. 551–4.

Chemical plants for processing radioactive materials are usually constructed of nickel-chromium stainless steel, and the material to be processed is generally in a nitric-acid or nitrate solution. The results of an investigation of (1) the fission-product contamination of niobium-stabilized 18-8 steel from nitric-acid solutions, and (2) the effectiveness of several reagents for removal of the fission products from the surface (i.e., decontamination) are discussed in this paper.

Contamination is either adsorbed on the surface or at worst does not penetrate deeply into the steel, and a large proportion of it may easily be removed. Treatment usually involves one or more of the following processes: detergent cleaning, formation of a soluble complex of the contaminant, solution of the contaminant in strong acid, and removal of the surface layers by physical or chemical means. Since many of these processes corrode the steel, investigation of corrosion effects is necessary in association with study of decontaminating efficiency.

The contaminating solutions used in this research were about $2M$ in nitric acid, and contained various fission products. Some included large amounts of uranium and a little plutonium, others did not; the β-active fission products were largely rare earths and the γ activity was due mainly to niobium and zirconium.

The paper contains graphs showing decontamination achieved by various treatments, and the following are among the general conclusions drawn:—

The most effective decontamination reagents are fluoride solutions: 3 per cent. hydrofluoric acid in 20 per cent. nitric acid is reported to give good results, with minimum corrosion. The next most effective reagent, which is relatively non-corrosive, is an alkaline tartrate-peroxide solution. Sodium hydroxide and alkaline tartrate solutions had been previously used, but the addition of hydrogen peroxide improves the effectiveness of such mixtures. Under the conditions generally used in these tests, nitric acid was the least potent decontaminating agent, but in treatment of stainless steel which had been exposed to an acid-deficient concentrated salt solution containing protactinium as well as fission products nitric-acid treatment was more effective. A 5 per cent. oxalic-acid solution proved, in the general tests, superior to nitric acid. It is noted that decontamination is improved by repeated treatment with several reagents.

H. H. HYMAN, R. C. VOGEL and J. J. KATZ: 'Decontamination of Irradiated Reactor Fuels by Fractional Distillation Processes, using Uranium Hexafluoride', pp. 613–26.

Heterogeneous reactors usually employ fuel elements which have only limited useful life, and when such elements are removed from a reactor they are intensely radioactive. In spite of the difficulties which this radioactivity introduces into re-processing steps, the uranium or other heavy-metal content of the fuel elements usually justifies decontamination and re-use.

Among the many techniques which have been proposed for uranium decontamination and recovery, those employing uranium hexafluoride are of particular interest. This paper briefly discusses the basic chemical information required in development of a uranium-hexafluoride separation process, and describes in detail a laboratory investigation of the conversion of uranium metal fuel elements to uranium hexafluoride, employing brominetrifluoride dissolution. Auxiliary problems associated with such an approach to uranium decontamination are also considered. Alternative methods which may be used for more refractory fuel elements are reviewed, and recent progress in fluorine technology is discussed, as affecting the probability of successful application of the chemical principles described in the paper.

One section describes a series of corrosion studies in conditions simulating those occurring in various stages of decontamination operations: these include

(1) *corrosion in interhalogen systems*, which demonstrated that nickel and high-nickel alloys such as Monel, K Monel and Inconel are highly suitable materials of construction,

(2) *corrosion by aqueous aluminium nitrate*, a solution liable to be used in removal of plutonium and fission products from a Monel or nickel vessel. It was shown that attack of Monel can be markedly inhibited by addition of sulphamic acid to the nitrate solution,

(3) *corrosion in cyclic exposure to aqueous and interhalogen systems*, in which specimens of nickel and high-nickel alloys showed a degree of resistance indicating the feasibility of cycling between interhalogen and aqueous systems of the types used,

(4) *corrosion in fused-salt melts*, in conditions simulating those obtaining in the dissolver vessel required in the fused-salt method of processing enriched reactor fuels. These tests demonstrated that corrosive attack is relatively severe, but that the simplicity of the method warrants the use of the solutions employed. Nickel and high-nickel alloys are the constructional materials which would be involved: nickel showed the best resistance, followed by Monel and Inconel in descending order.

Some experiments were also carried out to determine the behaviour of various materials in liquid bromine fluorides at elevated temperatures, and in gaseous fluorides and fluorine. The nickel, Monel and Inconel parts of apparatus used in these experiments proved stable in all the conditions used.

L. P. HATCH *et al.*: 'Processes for High-Level Radioactive Waste Disposal', pp. 648–58.

Waste-disposal problems in the field of atomic energy will depend, in considerable measure, on the type of chemical treatment used in the processing of spent uranium fuels. This paper describes two methods which have been studied at the Brookhaven National Laboratory, U.S.A. A detailed and well illustrated description is given of calciner pilot plant developed for processing high-level radioactive waste. Stainless chromium-nickel steel is extensively used in its construction, and it embodies an entrainment separator packed with stainless-steel mesh.

Effect of Nuclear Radiation on the Elastic Properties of High-Alloy Material

See abstract on p. 131.

Corrosion of Nickel in Molten Sodium Hydroxide

R. S. PEOPLES, P. D. MILLER and H. D. HANNAN: 'Reaction of Nickel in Molten Sodium Hydroxide.' *U.S. Atomic Energy Commission, Report* BMI-1041, 1955; 11 pp.

Sodium hydroxide is in many respects suitable for use as a heat-transfer medium in nuclear reactors, but some difficulty is being experienced in finding a container material which will resist attack by this corrodent at the temperatures involved.

In view of the good resistance of nickel to caustic at relatively elevated temperatures, research investigators working under the aegis of the U.S. Atomic Energy Commission and elsewhere have devoted much study to the corrosion attack suffered by nickel in molten sodium hydroxide, with the aim of discovering means by which such corrosion could be prevented, or so retarded as to make possible satisfactory use of nickel for containers.

This report contains the final experimental results obtained in a study of several phases of the nickel/sodium-hydroxide system. It is shown that sodium oxide is a product of the reaction of nickel and sodium hydroxide at 950°C., under either an argon or a hydrogen atmosphere. The authors discuss the rôle of sodium oxide in the corrosion mechanism.

This more detailed study of the nickel/sodium-hydroxide system at 950°C. under argon confirms suggestions made in an earlier report with regard to the occurrence of a cyclic corrosion process. A study of this system at 816°C. indicated that, in a given time interval, corrosion at the lower temperature is only about half as severe as that occurring at 950°C.

Nickel-containing Aluminium Alloy for Distilled-Water Service

J. E. DRALEY and W. E. RUTHER: 'Corrosion-Resistant Aluminium above 200°C.' *U.S. Atomic Energy Commission Report* ANL-5430, July 15, 1955; 37 pp.

This is the major paper reporting the investigation which led to development of an aluminium alloy resistant to the blistering corrosion to which pure aluminium and certain aluminium alloys are subject in distilled water above 200°C. (See also reference to report by the same author on p. 142.) Tests of two types, used in the experiments described, provided respectively, for static and moving immersion conditions. Technique and equipment are described.

Based on the observations made, and on protective effects resulting from coupling of the aluminium-base materials with stainless steel in distilled water and in various modified solutions, the authors advance an explanation of the blister-penetration attack, in terms of mechanical damage resulting from diffusion of corrosion-product hydrogen into the metal. In accordance with this hypothesis, work was initiated on various lines to develop methods of inhibiting corrosion. Some success was achieved by treatment of the water with cations which are reduced on the aluminium to form deposits of metals characterised by low hydrogen overvoltage, e.g., nickel. Kanigen (electroless) plating and electrodeposited coatings proved equally satisfactory.

The outstanding success of the experiment was, however, that obtained by addition of alloy elements to aluminium. In view of the conclusions drawn with reference to the mechanism of corrosion attack (see above), metals of low-hydrogen overvoltage

were studied, and, as was anticipated, nickel proved to be the most beneficial addition.

As a result of extensive experiments made to determine optimum composition, an alloy containing 1 per cent. of nickel is recommended. The influence of silicon and of iron in the nickel-containing alloys was also investigated; silicon was found to be detrimental, but moderate amounts could be tolerated in the simultaneous presence of iron or nickel. Further work on the effect of the addition elements is required before a final conclusion can be drawn.

Following the establishment of the optimum, 1 per cent. nickel composition, a study was made of the influence of method of production, treatment, etc., on its corrosion-resistance and mechanical properties. This material appears to be immune from penetration attack, and is recommended for use wherever its normal reaction rate with water or a solution is tolerable. In static distilled water penetration rates were approximately 1, 1½, 3 and 9 mils per year, respectively, at 250°, 290°, 315° and 350°C. Welded specimens of the alloy also gave satisfactory corrosion-resistance. Significant velocity of flow of the water past the metal gave rise to somewhat higher corrosion rates.

Reclaiming of Uranium-contaminated Metals

See abstract on p. 123.

Properties and Applications of Nickel and High-Nickel Alloys

See abstract on p. 129.

Nickel Alloys for Thermocouples

C. L. GUETTEL: 'New Thermocouple for Service in Reducing Atmospheres.'

Metal Progress, 1956, vol. 69, Apr., pp. 89-90.

Many of the thermocouple materials generally used are subject to deterioration when exposed to reducing atmospheres such as are now employed in many heat-treatment operations. The attack undergone seriously affects the recording, and excessively frequent calibration is necessary to maintain the necessary accuracy. This note refers to a new type of thermocouple which has been developed to obviate such difficulties. The nominal compositions of the alloys used for the positive and negative elements are, respectively,

	Positive	*Negative*
C ..	0·10 %	0·05 %
Si ..	1·00 %	3·0 %
Cr ..	20·00 %	—
Nb ..	1·00 %	—
Ni ..	Bal.	Bal.

It is claimed that a thermocouple of this type is stable in reducing atmospheres and that it has sufficient sensitivity of thermal e.m.f. to ensure the close temperature control required in modern heat-treatment. In addition, if after prolonged exposure to a reducing atmosphere the couple goes slightly off calibration, the thermal e.m.f. generated increases slightly and would cause only a small drop in the temperature of the furnace. Tests in conditions known to accelerate green-rot attack in some thermocouple alloys have confirmed the stability of the 242-33 type.

Although the thermal e.m.f. response of this couple is somewhat lower than that of other base-metal couples, its sensitivity (mv. per degree) is equivalent in the higher-temperature range for which it is specially designed. A comparison of the relation of e.m.f. and temperature for the new couple and for iron/Constantan, Chromel/Alumel and platinum/platinum-rhodium couples is shown in the paper.

(Attention is called to the increased chromium content of the alloy used for the positive element, which enhances resistance to oxidation and lengthens the life of the couple when used in oxidizing atmospheres.)

Titanium-Carbide/Nickel-Alloy Cermets

W. L. HAVEKOTTE: 'High-Temperature Parts based on Titanium Carbide.'

Metal Progress, 1956, vol. 49, Apr., pp. 56-61.

This paper contains information on cermets made by Firth Sterling, Inc., further to that published in 1953: see *Metal Progress*, 1953, vol. 64, Dec., pp. 67-70: abstract in *Nickel Bulletin*, 1954, vol. 27, No. 3, pp. 49-50.

This later paper gives details of the method of preparation of the titanium carbide, and of the production, composition and properties of ten cermets in which the amounts of carbide and the composition and amount of the metallic binder were varied within pre-determined ranges. The binder alloys were in all cases nickel-base, containing substantial amounts of chromium, with or without cobalt, and, in most cases, small percentages of molybdenum. Structure, physical properties, mechanical properties (at normal and at elevated temperatures), and oxidation-resistance (at 1800°F.: 980°C.) were determined as a function of composition. From the results of these tests and from other data available to the author, the following conclusions are drawn:—

'Densities, transverse rupture strengths, and impact-resistances increased with an increase in binder content, while stress-rupture strengths and hardnesses decreased.

'Oxidation-resistance increased (gain-in-weight decreased) as the amount of chromium was increased.

'Carbon content had an important effect on stress-rupture strength. In one case the 100-hour strength for a given cermet at 1800°F. (980°C.) fell from 13,500 p.s.i. to 7,000 p.s.i. as the carbon content increased from 9·5 to 11·4 per cent.

'The amount of chromium carbide in the microstructure affected the toughness. For example, the impact-resistance decreased from 5·7 to 3·2 ft.-lb. as the amount of chromium carbide increased from 0·5 to 13 per cent.'

As in earlier papers relating to this group of cermets,

some comparisons are made of their properties with those of the cast alloy X-40 (cobalt-base, containing chromium, nickel and tungsten). Fragility continues to be the major obstacle to extension of the use of cermet materials.

Nickel-Alloy/Ceramic Reactions at Elevated Temperatures

(1) W. D. KINGERY and F. H. NORTON: 'Study of Metal/Ceramic Interactions at Elevated Temperatures: Surface Tension of Iron-Nitrogen and Nickel-Indium Alloys.'

U.S. Atomic Energy Commission Publn. NYO 6296, 1954; 12 pp.

(2) F. H. NORTON and W. D. KINGERY: 'Study of Metal/Ceramic Interactions at Elevated Temperatures: Surface Tension of Nickel Alloys, Wetting, Wintering.'

U.S. Atomic Energy Commission Publn. NYO 4630, 1955; 15 pp.

Surface-tension measurements on some nickel-chromium and nickel-titanium alloys are reported, and in a study of the wetting and adherence of Al_2O_3, the metallic bonds used included nickel-cobalt-iron, nickel-titanium, nickel-zirconium, iron-nickel, and iron-nickel-titanium alloys.

For abstracts of both reports see *Metallurgical Abstracts*, 1956, vol. 23, Apr., p. 726.

See also

F. H. NORTON and W. D. KINGERY: 'Study of Metal/Ceramic Interactions at Elevated Temperatures.'

Quarterly Progress Report for Period ending Oct. 1, 1955.

U.S. Atomic Energy Commission Publn. NYO 4632, 1955; 7 pp.

Surface-tension/temperature coefficients were determined for iron-carbon, nickel-carbon, cobalt-carbon and nickel-titanium alloys, and for pure nickel.

Mechanical Properties of Stainless Steel at Low Temperatures

S. C. COLLINS, F. D. EZEKIEL, O. W. SEPP and J. W. RIZIKA: 'The Strength of Certain Stainless and Carbon Steels at Low Temperatures.'

Amer. Soc. Testing Materials, Preprint 74, June 1956; 13 pp.

Attention is directed to the large amount of data on the mechanical properties of metals, alloys and steels at sub-zero temperatures which has been accumulated as a result of work by various investigators. In many cases the tests have been made at only a few specific temperatures, e.g., the sublimation temperature of carbon dioxide (194·6°K.), the boiling point of oxygen (90·1°K.), or the boiling point of nitrogen (77·3°K.). The work reported in this paper comprises an extension of earlier investigations: tests were made over the range 300° to 10°K. (27° to −263°C.), without regard to the usual fixed points, and the test specimens were cooled by a stream of helium gas instead of by immersion in a liquid.

Two methods of tests were used, torsion and tension. A description is given of the helium cryostat used to provide the cold environment, with full details of test specimens and procedure.

The torsion tests were made on three types of steel, an annealed and a cold-rolled carbon steel, and an austenitic chromium-nickel steel in the annealed condition. For the tensile tests two '18-8' and one 25-20 chromium-nickel steels, and one ferritic stainless steel were selected as representative.

At the very low temperatures used some of the steels exhibited marked discontinuities in the stress-strain relationship, especially at low rates of strain. The sudden increases in length were fairly uniform in magnitude, and were independent of the length of the specimen. In some cases the material gained in strength after a number of such sudden increases, but in other cases this was not so. The improvement in room-temperature properties resulting from work hardening at low temperatures was found to depend (in the case, at least, of Type 303 steel) on the extent of the work hardening: for intermediate amounts the effect may even be negative. Further tests of a related type are projected, using brittle specimens, and an investigation is to be made of changes in microstructure, density and resistivity associated with low-temperature mechanical properties.

Stress-Strain Characteristics of Nickel-Alloy Steels

See abstract on p. 132.

Interrelation of Oxide Films and Corrosion-Resistance in Stainless Steels

T. N. RHODIN: 'Oxide Films on Stainless Steels.'

Corrosion, 1956, vol. 12, Mar., pp. 123t-35t; disc., p. 135t.

This paper reports a study of oxide films formed on various types of austenitic stainless steel and of the interrelation between these films and the corrosion characteristics of the steels. For this purpose the films are classified into three types, according to thickness, structure, and chemical composition.

The composition of oxide films isolated from the surfaces of stainless steels were studied in detail, using specially developed micro-analytical techniques. The effect of composition of the steel and surface treatment was considered in relation to films formed on three types of nickel-chromium austenitic steels, and the degree of resistance to attack by various acid and other media was correlated with the composition of the films formed on the respective types of steel. It is concluded that the composition of films after immersion in acids is related to that of the films existing prior to immersion: the effect of contact with the corrodent depended on the nature and intensity of the corrosive attack. Ultra-thin films associated with passivity of stainless steels are not necessarily enriched in chromium or nickel, although these elements form important constituents of the film. Depletion in

iron and enrichment in silicon is characteristic of ultra-thin films.

It is concluded that the properties of the films formed on the steels give good indication of the ability of the austenitic stainless types to develop corrosion-resistant surfaces in given environments.

Contact (Galvanic) Corrosion in Metals and Alloys: Reference Data

ADMIRALTY AND MINISTRY OF SUPPLY INTER-SERVICE METALLURGICAL RESEARCH COUNCIL, 'Corrosion and its Prevention at Bimetallic Contacts.'

Published by *Her Majesty's Stationery Office*, 1956; 5 pp. + tables. Price 1/6.

With foreword by PROFESSOR A. J. MURPHY.

It is pointed out in the foreword that although there now exists a large store of authoritative information on the intrinsic corrosion-resistance of metals and alloys in a wide variety of liquid and gaseous media, such data are usually based on tests in which an isolated specimen of the metal has been exposed to the corrosive medium. Departure from such conditions may profoundly affect the degree of corrosion attack.

A particularly significant variable in this connexion is the effect, on the corrosion of individual materials, of contact with metals and alloys of different types, and the Corrosion and Electrodeposition Committee of the Inter-Service Metallurgical Research Council, in considering this matter, reached the conclusion that published information is inadequate, and in some cases even misleading. A systematic correlation and evaluation of relevant data has therefore been made, under the aegis of this committee, and the results are published in this reference manual.

An introductory section (by DR. ULICK R. EVANS) summarizes the general principles involved in contact corrosion, the variables influencing effects produced on metallic materials, and some methods which may be used to minimize or prevent contact corrosion. A table, arranged in concise and usable form, shows the relative effects, on the corrosion of a range of materials, when they are brought into mutual contact and bridged by water containing an electrolyte.

The above information is supplemented by a list of the names, offices, and telephone numbers of individuals in the Admiralty and Ministry of Supply through whom designers and contractors can be put into touch with corrosion specialists, for consultation in cases of difficulty.

Electrolytic and Chemical Polishing Methods

See abstract on p. 122.

Constructional Materials for Use in Petroleum Refineries

J. F. MASON: 'The Selection of Materials for Some Petroleum-Refinery Applications.'

Corrosion, 1956, vol. 12, May, pp. 199t-206t.

The information given in this report, and the recommendations made, are based on extensive tests carried out in service conditions over a considerable period, and on reports of experience in various branches of the refinery industry.

Detailed tabular data, accompanied by critical and informative comments, give quantitative information on the performance of a large number of ferrous and non-ferrous materials in refinery conditions. The groups represented, in some or all of the tests reported, cover:—

Monel Alloys (standard, S, and K types)

Stainless Steels (straight and complex austenitic chromium-nickel and ferritic high-chromium stainless steels)

Copper-nickel and other copper-base alloys

Nickel-molybdenum-base alloys (Hastelloys A, B and C)

Nickel-silicon-aluminium alloy (Hastelloy D)

Aluminium alloy (aluminium 99·0 per cent. min.)

High-alloy cast iron (Ni-Resist)

Unalloyed cast iron

Mild steel

Silicon-iron alloy

Lead.

Data on behaviour of these materials in service conditions show their relative suitability for use in construction of plant employed in the following branches of the industry:—atmospheric crude distillation, distillation of products from thermal cracking, caustic treatment of petroleum products, acid treatment of distillates, sulphuric-acid and hydrofluoric-acid alkylations, and furfural recovery.

Particular attention is drawn to the high degree of corrosion-resistance offered by various nickel-containing materials in many of the conditions discussed.

Corrosion by Hydrogen Sulphide at High Temperatures

G. SORELL and W. B. HOYT: 'Collection and Correlation of High-Temperature Hydrogen-Sulphide Corrosion Data.'

N.A.C.E. Technical Committee Report, *Publn.* 56-7. *Corrosion*, 1956, vol. 12, May, pp. 213t-34t.

Severe corrosive attack by hydrogen-sulphide-bearing gas mixtures at elevated temperatures has been experienced on catalytic reforming and desulphurizing units in petroleum refineries. In view of the increasing number of such installations, this problem is of vital importance to the refining industry, and it is currently being studied experimentally in the laboratories of several companies. Service experience in commercial operation is also being collected and evaluated.

This report, comprising a correlation and critical review of relevant data, is contributed by the M. W. Kellogg Company of New York, to assist the N.A.C.E. work on sulphide corrosion. The material presented has been obtained from the published literature, and also from private sources: it covers a wide range of laboratory results, pilot-plant tests, and refinery experience.

The first part of the report consists of a critical survey of information, classified as shown below:—

Characteristics of sulphide scales
Appearance of scale, its physical properties and chemical composition: mechanism of scale formation.

Environmental factors affecting corrosion
Temperature, hydrogen-sulphide content, pressure, duration of exposure, influence of cyclic conditions, diluent gas, contaminants, metal pre-treatment, turbulence.

Materials of Construction
Carbon and low-chromium steels, intermediate chromium steels (11–13 per cent. chromium), straight-chromium and austenitic chromium-nickel stainless steels, nickel and nickel alloys, aluminium, aluminium alloys and aluminium coatings, miscellaneous alloy steels.

Correlation of Corrosion data.

The following points are culled from the general summary of this section of the report:—

'Carbon steel and chromium-molybdenum steels are attacked with equal severity by gas mixtures containing hydrogen sulphide as the principal corrodent. The 12 per cent. chromium steels offer moderately higher resistance, but the degree of improvement is erratic and unpredictable. The stainless steels, particularly the chromium-nickel grades, are considered to possess excellent resistance: although they are not entirely immune from attack, they stand up well consistently in even the more severely corrosive environments normally encountered.

'Aluminium, iron-aluminium alloys, and various aluminium-rich surface coatings show negligible corrosion rates in hot gas mixtures containing hydrogen sulphide.

'Amounts of hydrogen sulphide present in the majority of desulphurization units are sufficiently high to cause severe scaling of carbon and low-alloy steels at reactor temperatures. In locations where protection is required the 18-8 chromium-nickel stainless steels are generally considered to be the optimum choice of material.

'The quantities of hydrogen sulphide present in catalytic reforming units are usually of such a low order that carbon or low-alloy steels are adequately resistant, but in some instances, particularly where no provision has been made for pre-desulphurizing the feed or for scrubbing the recycle gas, some measure of protection is required. Here also 18-8 chromium-nickel steels are favoured, in view of the inconsistent performance of the 12 per cent. chromium steels.

'Nickel and high-nickel alloys deteriorate rapidly in hydrogen-sulphide-containing atmospheres at elevated temperatures: the attack is in the form of severe intercrystalline sulphidation. Straight-nickel steels are attacked fairly rapidly.

'In chromium-nickel steels the chromium : nickel ratio is considered to be a better criterion than the absolute nickel content for predicting corrosion-resistance. Satisfactory behaviour is likely, provided that the chromium : nickel ratio does not fall below about 0·5, but this proviso is beneficial only up to certain contents. Very high ratios again tend to diminish corrosion-resistance, a fact which can be deduced from the relative inferiority of straight-chromium steels as compared with the 18–8 chromium-nickel grades.'

Part 2 of the report comprises a series of abstracts (many of which include tables and graphs) summarizing information obtained from the literature and from private sources.

E. B. BACKENSTO, R. D. DREW, R. W. MANUAL, J. W. SJOBERG: 'High - Temperature Hydrogen - Sulphide Corrosion in Thermofor Catalytic Reformers.'
Corrosion, 1956, vol. 12, May, pp. 235t–44t. *N.A.C.E. Publn.* 56–8.

This report is contributed, also in aid of the work of the N.A.C.E. Committee, by Socony Mobil Oil Company, Inc.

Catalytic reforming is one of the key processes employed in the manufacture of modern high-octane petrol: several competitive catalytic reforming processes have been developed and put into commercial operation. Although all these procedures have a common purpose, they vary considerably in the catalyst used and the conditions obtaining, e.g., in physical arrangement and process flow. The type of charge stock which they can handle most efficiently may also vary.

The Thermofor catalytic reforming process was developed by Socony Mobil Oil Company for handling a wide variety of charge stocks, including high-sulphur, low-quality gasoline. This process employs the moving compact bed principle used in the Thermofor catalytic cracking process. The catalyst consists of synthetic beads of chromia and alumina, and is regenerated continuously during the process. When the charge naphtha contacts the catalyst in the reactor, desulphurization of the feed is accomplished, the sulphur being converted mainly to hydrogen sulphide. Because some of the hydrogen sulphide is returned in the hydrogen-rich recycle gas stream, the level of the sulphide in the gas recycle system and the reactor effluent can be relatively high.

Orginally construction materials for the commercial TCR units were selected largely from commercial low-chromium steels, which are commonly used in other petroleum equipment for protection against high-temperature corrosion by sulphur-bearing oils. These steels were known to resist high-temperature hydrogen attack, and it was expected that they would exhibit reasonably good resistance to hydrogen sulphide, but it was found that at the temperatures and pressures involved in the TCR plant hydrogen sulphide caused unexpectedly rapid scaling. After relatively short service, measurements of metal loss indicated corrosion of 0·25 i.p.y. or more.

The problem was studied by two methods:—laboratory tests were made on a series of specimens ranging from carbon steel to 25–20 chromium-nickel stainless steels, in conditions simulating reforming and hydrogenation operations, and, parallel

with these tests, exposures were made in commercial catalytic reforming units. The results of the laboratory tests have already been reported: see *Corrosion*, 1956, vol. 12, pp. 6t–14t: *Nickel Bulletin*, 1956, vol. 29, No. 3, p. 51. The present paper summarizes the results of initial corrosion tests in two TCR commercial units handling widely different types of charge stock. The observations made confirm the results of the laboratory tests, showing that only the 18–8 and higher chromium–nickel steels give satisfactory resistance in the conditions indicated. Reduction of the hydrogen-sulphide concentration, and the use of aluminium-coated steels, are further means which may be adopted to combat this type of corrosion.

Steel Specifications: Ministry of Defence Grouping

See abstract on p. 133.

Corrosion-Resisting Characteristics of Cast Irons

See abstract on p. 131.

Welding of Stainless-Steel Tubes to Tube Sheets

W. R. SMITH: 'Joining Tubes to Tube Sheets for Corrosive Radioactive Chemical Service.'

Welding Jnl., 1956, vol. 35, Apr., pp. 307–10.

Joining of tubes to tube sheets, in the fabrication of tubular heat exchangers, has always presented problems of considerable difficulty, and these are particularly acute in the fabrication of exchangers for radioactive chemical process service, where absolute integrity must be maintained and no maintenance repair is possible. This article describes methods which have been developed for joining of stainless-steel tubes to tube sheets for this type of equipment. Two specific conditions are provided for: (1) joining in tubular heat exchangers in which the corrosive medium passes through the inside of the tubes, with the steam on the outside, and (2) exchangers in which the steam passes through the tubes and the corrosive medium is on the outside. The latter case presents special difficulties, in that the 'crevice' which exists between the tube and the sheet may give rise to crevice corrosion, leading to premature failure in many chemical solutions. The design and joining procedure are described and illustrated, and typical property data indicate the satisfactory nature of the joints produced. It is stated that the procedure is economical and that a minimum of skill is required on the part of the operator.

High-Temperature Rupture Properties of Welded Joints in Inconel

D. A. SCOTT: 'Rupture Properties of Inconel Weldments at 1400°, 1600° and 1800°F.'

Welding Jnl., 1956, vol. 35, Apr., pp. 161S–3S.

The samples examined comprised 4-in. × 11-in. × ¾-in. plate, the welds being made along the 11-in. edges. The material was welded in two conditions: (1) hot-rolled, and annealed for two hours at 1650°F. (898°C.), i.e., fine-grained material, and (2) treated as in (1), but afterwards grain-coarsened by heating for two hours, at 2050°F. (1120°C.). Two welding methods were employed: (1) coated-electrode metallic-arc, and (2) inert-gas consumable-electrode: the former method was used for welding the plate in both conditions, the latter for the fine-grained plate only.

Specimens of the plate, in both conditions, of the weldments, and of weld metal, were tested in standard creep-rupture machines at the three temperatures named. The results were as follows:—

At 1400°F. (760°C.) joint efficiencies up to 10,000 hours rupture life were 100%.

At 1600°F. (870°C.) joint efficiencies varied between 100% at 500 hours and 80–85% at 10,000 hours rupture life.

At 1800°F. (980°C.) inert-gas joint efficiencies were in all cases 95%: metal-arc joints varied as shown below,

(*a*) in fine-grained plate 85% at 500 hours to 100% at 10,000 hours rupture life,

(*b*) in coarse-grained plate 75% at 500 hours to 85% at 10,000 hours rupture life.

Post-welding treatment of fine-grained plate weldments at 2050°F. (1120°C.) for two hours resulted in marked improvement in rupture life of the weldments at 1800°F. (980°C.) and high stress levels.

Welding, Brazing and Soldering of High-Nickel Alloys

See abstract on p. 130.

Clad Steel Plate: Production, Properties, Fabrication

J. ERSKINE: 'Clad Steel Plates.'

Nuclear Engineering, 1956, vol. 1, June, pp. 97–100.

The general chemical and other advantages of clad steel plate are briefly reviewed, and production and processing of clad steel of various types is described, as exemplified by Colclad, a composite sheet material made by Colvilles, Limited. Reference is made also to ultrasonic and bend test methods used to check the bond between the base and the cladding.

Methods recommended for processing clad steel sheet are then considered, with special reference to hot- and cold-working and welding procedure. The satisfactory service record of clad-steel components to date presumes increasing use of such material in the future.

Welding of Clad Steels: Recommended Procedure

J. HINDE: 'The Welding of Clad Steels.'

Welding, and Metal Fabrication, 1956, vol. 24, Jan. and Feb., pp. 11–15 and 59–62.

This paper, originally read before La Société des Ingénieurs Soudeurs, in Paris, deals exclusively with the welding of clad plate available as a rolled product consisting of a backing of mild or low-alloy steel on which is integrally bonded (on one or both sides) a cladding of nickel, Monel, Inconel or stainless steel.

After brief introductory notes on methods used for

production of clad materials, and on the varieties of clad product available, detailed consideration is given to the welding technique suitable for the respective types. A review is made of problems associated with welding of such composites, with general recommendations as to the choice of welding method, set up and alignment of joints, and procedure desirable in downhand butt welding, vertical and overhead butt welding, and fillet and other types of welded joints which may be required for some special applications. It is noted that in welding of clad steels neither the resistance method nor gas welding finds general application. In some instances an all-weld deposit similar to the cladding material is used, but in most cases welding involves separate treatment of the steel base and the cladding. Metal-arc welding is by far the most generally used method: inert gas-arc methods have been applied to the cladding, and the submerged-arc technique has been used for the steel base.

The later sections of the paper comprise practical details of conditions requisite for welding individual types of clad material, in various thicknesses. The text is illustrated with tables and figures showing preferred methods for joining nickel-, Monel-, Inconel-, and stainless-steel-clad steels.

Code requirements which are laid down to ensure soundness, strength and ductility in weld material and welded joints are reviewed, with notes on the possible causes of defects which may be revealed by such tests. The paper closes with a short discussion of precautions which should be observed during heat-treatment of welded clad materials.

Reprints of this paper will shortly be available for distribution.

H. THIELSCH: 'Welding Composite Steels: Clad Steels.' *Machine Design*, 1956, vol. 28, May 3, pp. 96–100.

A practical, well-illustrated article, showing joint design, welding procedures, and compositions of electrodes and welding rods recommended for joining clad steels. Particular attention is given to the welding of stainless-steel-clad steel, but recommendations are made also for other combinations.

Weld-Cracking Test:
Evaluation of Nickel-containing Materials

See abstract on p. 123.

PATENTS

Electrolytic Refining of Nickel

Honeycombing liable to occur in electrolytic anodes produced from chloride-containing electrolytes is prevented by adding to the solution 0·00025–0·001 (preferably 0·0004–0·0008) g./L. of polyethylene oxide condensates of m-methyl p-octyl phenol containing 8–11 moles of ethylene oxide per mole and/or polyethylene oxide condensates of lauryl alcohol containing 4–6 moles of ethylene oxide per mole. The preferred composition of the electrolyte is (g./L.) nickel 40–60, sodium 18–30, sulphate radical 65–99, chloride radical 27–51, boric acid 15–25. The pH of the solution is 3·8–4·6.

MOND NICKEL CO., LTD. *Brit. Pat.* 749,135.

Preparation of 'Raney'-Type Catalysts

An alloy containing nickel 20–50, iron 1–7, per cent., aluminium balance, is melted, cast, ground, and treated with an alkaline solution, to produce a catalyst.

K. K. KAWAKAMI KENKYUJO. *Japanese Pat.* 2166/56.

Electrodes for Accumulators

Electrodes for electrolytic condensers and similar devices embodying electrodes of film-forming material consist of a mat of unwoven fibres or filaments, preferably of glass, individually sheathed with an impervious smooth metal. The sheathing, which is preferably of nickel and of a thickness about 0·0001 in., is produced by thermal decomposition of nickel carbonyl at 180°C.

J. B. BRENNAN. *Brit. Pat.* 747,962.

Nickel and Nickel Alloys in Cathode-Ray Tubes

Deformation of the nickel end portion of a cathode at operating temperatures is prevented by reinforcing it with stainless steel, tungsten, molybdenum, nickel–chromium–iron alloy, or nickel–copper alloy.

ELECTRICAL AND MUSICAL INDUSTRIES, LTD. (inventor, L. A. WOODBRIDGE). *Brit. Pat.* 749,256.

Extraction of Iron from Nickel Powder

Iron is removed from nickel powder by washing it in a 1–20 per cent. aqueous solution of formic, acetic, lactic or tartaric acid. The preferred solution contains 2–5 per cent. of formic acid. Treatment is at 20°–100°C. (preferably 20°–35°C.), for 1½–2½ hours, after which the solution is filtered.

J. W. GLENN, assignor to UNITED STATES ATOMIC ENERGY COMMISSION. *U.S. Pat.* 2,733,142.

Bright Nickel-Plating Solution

An improved type of bright nickel-plating solution consists of an aqueous acid solution of a nickel salt and 0·02–3 g./L. of a water-soluble acetylenic hydroxy compound, preferably 0·1–1 g./L. of 2-butyne-1,4-diol and 1–40 g./L. of naphthalene trisulphonic acid or salt thereof.

HANSON-VAN WINKLE-MUNNING CO.
Brit. Pat. 747,908 (similar to *French Pat.* 1,096,351.)
(„ „ *Italian Pat.* 513,086.)

Nickel Plating of Heat-Treatable Steels

A method of nickel plating directed particularly to the coating of hardenable rolled and drawn products in carbon and alloy steels, e.g., strip and wire, consists in plating the steel and subsequently

heating the plated material in the range 1450°–1650°F. (785°–845°C.), quenching, and tempering. This treatment hardens the steel, ensures intimate bonding between the nickel coating and the base, and gives a plating which is substantially free from embrittlement.

M. M. RUBIN, assignor to PITTSBURGH STEEL CO. *U.S. Pat.* 2,731,403.

Electrodeposited Nickel as Underlay for Diffusion Coatings

Surfaces which could not be directly coated by diffusion are treated by forming on them an intermediate metal coating, preferably of electrodeposited nickel, which is diffusible into the base, and on which is formed a layer of the outer coating metal (e.g., chromium or molybdenum) by formation of an iodide of that metal.

DIFFUSION ALLOYS, LTD. (inventors, R. L. SAMUEL, J. D. SAMUEL and N. A. LOCKINGTON). *Brit. Pat.* 749,840.

Production of Diffusion Coatings of Chromium on Nickel

Base metals, preferably iron or steel, into the surface of which chromium is to be diffused, are heated in the presence of a fluoride or iodide of chromium and an oxide of chromium. In one example cited, nickel strips are packed in a mixture of chromium 30 parts, chromium oxide 70 parts, ammonium fluoride 1 part, using a box made from nickel sheet. It is stated that after heating at 1100°C. for four hours, the nickel strip was clean and bright and showed a nickel-chromium surface coating to a depth of 0·003 in.

DIFFUSION ALLOYS, LTD. (inventors, R. L. SAMUEL and N. A. LOCKINGTON). *Brit. Pat.* 749,056.

Electroless Deposition of Nickel

In the chemical deposition of nickel on a catalytic material the bath consists of an aqueous solution of nickel ions, hypophosphite ions, a complexing agent (preferably an NH_4 compound, e.g., NH_4OH) and an additional stimulating agent, *viz.*, a monocarboxylic aliphatic saturated acid with a simple short chain of 3–5 carbon atoms and/or one of its salts. Preferred acids: lactic and propionic, propionic and amino-acetic, butyric and amino-acetic, valeric and amino-acetic. The pH of the bath is 4·5–7 and it is operated at 90°C.

GENERAL AMERICAN TRANSPORTATION CORPN. (inventors, G. GUTZEIT, P. TALMEY and W. G. LEE). *Belgian Pat.* 543,996 (addition to 525,625).

Chemical Coating of Steel to Improve Working Characteristics

Surface coatings which facilitate cold working of steels, chromium, nickel, and nickel-chromium alloys (e.g., in drawing or extrusion) are produced by treating the surface with an aqueous solution of P_2O_5 (preferably 6–8·5), $C_2O_4H_2$ (40–100) and H_2S (0·02–0·05) g./L. Mn 2·3 and/or Fe 3·5–15 g./L. may also be present. The pH of the solution is 7·5–8·7: operation is at 15°–99°C., with an immersion period of 2–40 minutes.

COMPAGNIE D'APPLICATIONS CHIMIQUES À L'INDUSTRIE and M. PETROFF. *Brit. Pat.* 748,383.

Nickel-Silver Electrodes for Storage Batteries

Limitations inherent in silver positive electrodes of storage batteries are overcome by the use of a sintered porous mass containing nickel as well as silver. The nickel powder used is preferably a finely divided type as obtained by thermal decomposition of the carbonyl. It is mixed with a silver-providing substance, preferably silver oxide. The interstices of a supporting member, preferably made from nickel-plated gauze or perforated nickel foil, are filled with the nickel-silver mixture, and are sintered, preferably at 700°–900°C., in a reducing atmosphere. It is claimed that increased efficiency, longer life, and other advantages are thus obtained.

STÉ DES ACCUMULATEURS FIXES ET DE TRACTION. *Brit. Pat.* 746,578.

Nickel-Aluminium-Iron-base Permanent-Magnet Alloys

Permanent magnets which show a high degree of anisotropy and give high values of BH_{max} are made from iron-base alloys containing aluminium 5–11, nickel 10–20, cobalt 10–25, copper up to 7, silicon 0·2–0·3, per cent., balance iron. It is specified that the nickel shall be more than the aluminium, and that silicon is greater than 0·6—one-fiftieth of the cobalt content. The preferred range is given and many typical compositions are listed, with their respective properties. The alloy is magnetized while cooling through the Curie point.

PHILIPS ELECTRICAL INDUSTRIES, LTD. (inventors, W. T. DEAN and A. STUTTARD). *Brit. Pat.* 750,015.

Heat-Treatment of High-Permeability Nickel Alloys

Mumetal (nickel 75–77, copper 4–5, chromium 1–2, per cent., iron balance) is formed into strip, which is annealed at 1550°–1650°F. (845°–900°C.) in hydrogen, to impart high permeability at flux densities below 100 gauss. The step of cold rolling to a thickness of 0·14 in., prior to annealing, is also claimed.

J. H. CREDE and J. P. MARTIN, assignors to ALLEGHENY LUDLUM STEEL CORPN. *U.S. Pat.* 2,728,697.

Magnetic Recording Wire

Magnetic recording wire is made by cold working, to a diameter of 0·004 in., an alloy containing copper 70–75, nickel 10–20, iron 5–15, per cent., and subsequently ageing the wire at 450°–800°C. until it shows a coercivity of 200–350 oersteds and a residual

induction of 1,000–3,500 gauss. It is specified that the nickel: iron ratio should be 1–3 : 1.

M. CAMRAS and E. S. BUMPS, assignors to ARMOUR RESEARCH FOUNDATION OF ILLINOIS INSTITUTE OF TECHNOLOGY. *U.S. Pat.* 2,733,175.

Metal-Glass Sealing Alloys

The metal part of a seal used with soft glass is made from an alloy containing nickel 42, chromium 4–8, titanium 1–3, per cent., iron balance.

H. M. McCULLOUGH, assignor to SYLVANIA ELECTRIC PRODUCTS, INC. *U.S. Pat.* 2,730,260.

U.S. Patent 2,471,079 specified a nickel-iron base sealing alloy in which niobium was present. According to the modification covered by the present patent, titanium is substituted for niobium. It is claimed that equivalent glass-sealing properties are achieved with the modified alloy, and that an improvement in surface characteristics is obtained, permitting better wetting of the surface by alloys of very low melting point, e.g., solder. The limits of composition specified are:—nickel 30–60, carbon 0–0·07, silicon 0·25–1, manganese 0·5–2, titanium 0·3–0·7, per cent., iron balance.

C. POST and W. S. EBERLY, assignors to CARPENTER STEEL CO. *U.S. Pat.* 2,730,443.

Ceramic-Metal Seals

Ceramic-metal seals of improved type are produced by the following method, which is claimed to be simpler and more economical than procedures previously used:—

(1) The ceramic part is coated with a suspension of finely divided interstitial metallic carbide material, preferably tungsten carbide or a mixture of the carbides of tungsten and titanium, (2) fired in a hydrogen-containing atmosphere, resulting in formation of a strongly adherent layer of the carbide material, which by this treatment is partially or wholly converted to metal, (3) metallized with nickel (or cobalt or iron), and (4) plated with silver.

The metal member of the seal is a 42 per cent. nickel nickel-iron alloy. It is prepared for sealing by being nickel plated and silver plated, and fired at 1050°C. in hydrogen. The two prepared surfaces are joined by brazing at 1050°C., in hydrogen, using silver as the brazing medium.

FERRANTI, LTD. (inventors, E. J. WHITMORE and K. A. MACDONALD). *Brit. Pat.* 746,963.

Protective Lubricating Coatings for High-Temperature Alloys

Protection from scaling during hot working, combined with lubricating action, is provided for high-temperature materials by means of a coating composed of a lacquer containing one or more resins of the silicone melamine or epoxy resin groups, in which finely ground particles of a fusible medium are carried in suspension. Coatings suitable for use on nickel-chromium-cobalt alloys, or titanium, are of the following composition: silica 30–55, red lead (Pb_3O_4) 30–50, potash (K_2CO_3) 10–20, potassium nitrate up to 2, arsenic oxide up to 1, borax up to 5, per cent. The potash may be replaced wholly or in part by sodium carbonate. The lacquered part is heated at a moderate temperature to drive off the liquid carrier and harden the resin, and when the part is heated in the forging furnace the resin is vaporized and the particles of the coating are fused together on the surface, forming a thin protective film which ensures freedom from deleterious oxidation.

ROLLS-ROYCE, LTD. (inventors, D. W. HALL and G. O. ECCLES). *Brit. Pat.* 749,641.

For hot-working of nickel-chromium-base alloys, e.g., by extrusion, a thin coating of nickel is applied, preferably by electrodeposition. This coating acts as a lubricant, and by such treatment it is possible to obtain a greater degree of deformation with a given hot-working load, thus reducing the number of applications of pressure required to forge a part, e.g., a turbine blade. With the nickel coating it is also possible to work at a temperature above that previously adopted, without undue growth of grain size. A further advantage of the coating is that the surface of the blank worked is protected from oxidation.

ROLLS-ROYCE, LTD. (inventors, D. W. HALL, G .L. TALBOT and G. O. ECCLES.) *Brit. Pat.* 749,909.

Precipitation-Hardening Chromium-Nickel Stainless Steel

The following composition is claimed for a hardenable stainless steel:—carbon 0·03–0·15, chromium 12–20, nickel 2–20, manganese 0·25–10, aluminium up to 1, titanium 0·25, niobium 1, per cent., balance iron. The structure of the steel partially transforms to α-ferrite on cooling after thermal treatment, and it is claimed that the material is substantially free from non-metallic nitride and cyanonitride inclusions.

M. H. PAKKALA, assignor to UNITED STATES STEEL CORPN. *U.S. Pat.* 2,738,267.

Cladding of Nickel-Chromium Alloys

In producing clad materials consisting of a thin layer of nickel united to a sheet of nickel-chromium or nickel-chromium-iron alloy, difficulties are experienced in obtaining adhesion, due to the formation of chromium oxide. Such difficulties are increased by aluminium and titanium, as present, for example, in creep-resisting alloys. According to this patent satisfactory cladding is obtained by the following method:—

A relatively thin sheet of nickel is applied over the

surface of a relatively thick sheet or bar of nickel-chromium or nickel-chromium-iron alloy, the assembly is heated in a reducing atmosphere to a temperature sufficiently high to cause the thin sheet or bar to weld together under pressure, and the assembly is hot rolled to form it into a composite sheet.

A further claim relates to sheets, produced in the manner described, which comprise composites having copper in the middle and nickel-chromium alloy sheets on the outside.

HENRY WIGGIN AND CO., LTD. (inventor, P. G. TURNER). *Brit. Pat.* 748, 499.

Cladding of Steel with Chromium Steel

In a process for roll-weld plating of unalloyed or low-alloy steel with a high-chromium steel, an intermediate layer of nickel or nickel alloy is applied, preferably by spraying, after the basis material has been sand blasted.

RHEINISCHE RÖHRENWERKE, A.G. *Brit. Pat.* 746,885.

Production of High-Alloy Powders by Grinding

Production of high-chromium alloy powders is facilitated, and thereby made more economic, by utilizing the sigma-phase embrittlement producible in such alloys by heating at about 800°C. The material, thus embrittled, is then crushed and/or ground to powder. The slag-forming portion of a welding electrode may be produced from such powder. Typical examples of suitable alloys include one containing chromium 43, nickel 21, titanium 2, niobium 4, tantalum 1, per cent., iron (with a small amount of carbon) balance.

WÄRGONS AKTIEBOLAG. *Brit. Pat.* 749,472.

Production of Nickel-Chromium Alloy Powders

Treatments used for the production of powdered forms of certain metallic materials are unsuitable for making powders from precipitation-hardening nickel-chromium and nickel-cobalt-chromium alloys, but satisfactory results can be obtained by the following procedure:—

The alloy, produced by conventional methods, is (1) heat-treated at a temperature which causes the precipitable phase to go into solution, (2) rapidly cooled to maintain the solution condition substantially completely, and (3) aged so as to harden without causing carbide precipitation at the grain boundaries. The alloy so treated is then immersed in a mixture of hydrofluoric acid and an oxidizing acid, preferably nitric acid. The range of alloys for which such treatment is particularly suitable falls within the following limits of composition:—nickel + cobalt 50–80 (nickel 40 min., cobalt 30 max.), chromium 5–30, molybdenum 0–10, iron 0–10, titanium 0·1–8, aluminium 0·1–8 (titanium + aluminium 0·5 min.), carbon up to 0·25 per cent., with or without other elements commonly present in nickel-chromium heat-resisting alloys having a precipitable $Ni_3(TiAl)$ phase.

MOND NICKEL CO., LTD. (inventor, A. W. FRANKLIN). *Brit. Pat.* 746,775.

Attention is drawn to the fact that many of the names of materials mentioned in The Nickel Bulletin are *Registered Trade Marks*.

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